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MEMO

TO: R.M. Solman
Process Manager
NO_X/VOC Consultation Office

FROM: P.G. Finlay
Co-ordinator
NO_X/VOC Control Technologies Work Group

DATE: January 15, 1990

RE: NO_X/VOC Control Technologies Summary Report

As part of the public consultation phase for the Development of a National Nitrogen Oxides (NO_X) and Volatile Organic Compounds Management Plan for Canada, attached is the following report:-

> **Summary Report:** "Control Technologies for Management of Nitrogen Oxides (NO_X) and Volatile Organic Compounds (VOC) in Canada," prepared for Federal Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee, Canadian Council of Ministers of the Environment (CCME), prepared by public consultations Work Sub-Groups on NO_X/VOC Control Technologies, January, 1990.

A draft of the summary report was distributed for review to the members of the four Control Technology Work Sub-Groups involved. Comments were requested by Friday 5 January, 1990, and those received are reflected in the final report to the extent possible in the time available.

Individual reports have also been prepared by the four Control Technology Work Sub-Groups. These reports are:-

> **Work Sub-Group 6.1:** Mobile sources - NO_X and VOC (Chair: F. Lavallee)
>
> **Work Sub-Group 6.2:** Stationary Sources - NO_X (Chair: P.Pinault)
>
> **Work Sub-Group 6.3:** Large Stationary Sources - VOC (Chair: B. Made)
>
> **Work Sub-Group 6.4:** Product Substitution and Miscellaneous Sources - VOC (Chair: L.A. Dwyer)

In general, the participation and contributions from various sub-group members has been excellent, especially when the short time frame and busy schedules of individuals are considered. Consensus and agreement has been reached on many topics. However, many believe that more time and more investigations would result in better information and in better decisions.

As a minimum, the Control Technologies work-groups has provided stakeholders with opportunities to contribute their expertize and perspectives to the public consultation process. This will help the development of a NO_x/VOC Management Plan for Canada.

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93-01992/

ABSTRACT

Emissions standards and technologies for the control of Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOC), are outlined. Controls of mobile and stationary sources are discussed, and the effectiveness and costs of some control options, are indicated. Conclusions and recommendations are presented from various stakeholders, as part of the development of a Canadian Council of Ministers of the Environment (CCME) Plan for the Management of NOx and VOC in Canada.

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CONTROL TECHNOLOGIES
FOR
MANAGEMENT OF NITROGEN OXIDES (NO_X) AND
VOLATILE ORGANIC COMPOUNDS (VOC) IN CANADA

1. INTRODUCTION

In October 1988 the Canadian Council of Ministers of the Environment (CCME) instructed that a National Nitrogen Oxides (NO_X) and Volatile Organic Compounds (VOC) Management Plan be developed for Canada. The Plan is to achieve Canada's own environmental requirements and to meet international obligations. The Federal/Provincial Long Range Transport of Air Pollutants (LRTAP) Steering Committee was instructed to consult with all interested stakeholders, and to develop the Plan by October 1990.

In August 1989, technical briefings were held in Calgary, Alberta and Montreal, Quebec for interested stakeholders. In September 1989, a multi-stakeholder workshop was held in Ottawa, Ontario. Following the workshop, various multi-stakeholder work groups were formed to investigate further specific issues, and to report to the LRTAP Steering Committee by December 15, 1989.

The six Work Groups and their topics were:

Work Group 1: Modelling
Work Group 2: VOC/NO_X Impacts
Work Group 3: Apportionment
Work Group 4: Public Education
Work Group 5: Energy Efficiency/Conservation/Lifestyles
Work Group 6: Control Technologies

For the technical briefings in August 1989, various CCME reports for the development of the NO_X/VOC plan were provided including information on NO_X and VOC Control Technologies (1,2,3).

Four Work Sub-Groups were formed to investigate further NO_X and VOC Control Technologies as shown below:

Work Sub-Group 6.1: Mobile Sources - NO_X and VOC
Work Sub-Group 6.2: Major Stationary Sources - NO_X
Work Sub-Group 6.3: Large Stationary Sources - VOC
Work Sub-Group 6.4: Miscellaneous Stationary Sources - VOC

The Sub-Groups included representation from various governments, industries and non-government groups (see Annex 1 for list of members). Addresses telephone and FAX numbers of Sub-Group members, are available from the NO_X/VOC Consultations Office.

Generally, all work groups were asked to consider the relevance and feasibility of their deliberations to the overall Management Plan requested by the Canadian Council of Ministers of the Environment. The Work Groups provided an opportunity for stakeholders to provide their perspectives, expertize, concerns and suggestions to the development of the Plan.

The major objectives suggested for the Control Technologies Work Sub-Groups were (4):

(i) **To improve on the technical information provided in the CCME Technical Annex II and III on NO_X and VOC Emissions Control Technologies (dated July 1989).**

(ii) **To identify source sectors for possible emission performance standards.**

(iii) **To recommend, if possible, emission performance standards for specific sources.**

When the various Sub-Groups were formed, they developed their own terms of reference and appointed chairs from their membership to lead the Sub-Group activities. Due to the short time available for the Sub-Groups to meet, consult and to produce reports, most of the efforts tended to focus on the status of various control technologies.

This Summary Report is intended to extract information provided from the Work Sub-Groups and from other sources, that will be of direct use in the Development of NO_X/VOC Management Plan.

Section 2 of this report provides an overview of the status of standards for the control of NO_X and VOC emissions in various jurisdictions.

Section 3 provides information on Control Technologies (additional to the information in the CCME Technical Annex, July 1989).

Section 4 includes specific conclusions and recommendations provided by the various Sub-Groups.

A draft of this Summary Report, dated 15 December 1989, was issued for review and comment. Members of the various Work Sub-Groups, were requested to provide their input by 5 January, 1990. Separate reports were prepared by each of the four Work Sub-Groups, and are available. (9.1, 9.2, 9.3, 9.4).

Comments on the draft Summary Report were received from representatives of the Engine Manufacturers Association, Transport 2000, Canadian Electrical Association (Nova Scotia Power, Alberta Power Ltd.), Coal Association of Canada (Trans Alta Utilities Corp.), Energy, Mines and Resources Canada (CANMET), Turbo Resources, Petro-Canada, and B.H. Levelton and Associates Ltd. All these comments were considered and some were discussed with the individual reviewers. The final report reflects these contributions to the extent possible in the time available.

2. STANDARDS

In October 1988 Canada and 24 other countries signed an international protocol under the auspices of the United Nations Economic Commission for Europe (UN ECE). The protocol includes the following basic provisions (5):

- a freeze in NO_X emissions at 1987 levels by 1994
- **application of national emission standards based on best available technology economically feasible (BATEF) to major new mobile and major new stationary sources (or source categories)**
- additional control measures for major existing sources, and
- by January 1, 1996, a program for further reductions based on critical load to the environment.

A UN ECE protocol is now being negotiated for the control of Volatile Organic Compounds (VOC). It is expected that this protocol may also include provisions to apply national emission standards based on best available technology economically feasible or achievable (BATEA).

A range of possible technologies for the control of various sources is expected to satisfy the obligation of protocol signatories to applying BATEA emission standards.

Traditionally, many jurisdictions in Canada regulated emissions by stipulating only that local air quality objectives be satisfied by a proponent for a new facility, or by the owner of an existing facility.

Virtually all environmental regulatory agencies in Canada have some ambient air quality objectives, air quality criteria, point of impingement or ground level concentration limitations. For example, under the Canadian Environmental Protection Act, ambient Air Quality Objectives have been published for Nitrogen Oxides (NO_X), Sulphur Dioxide (SO_2), and Ozone (O_3) (6). These objectives for desirable, acceptable and tolerable ranges were developed by the Federal/Provincial Air Quality Advisory Committee, and are periodically revised as new information and considerations emerge. Almost all provincial agencies have either air quality criteria or ground level concentration limitations (typically for 1 hour, 24 hours, and annual averages) (7).

In addition to ambient air quality requirements, "bottom of stack","end of pipe" or "tail-pipe" emission standards for a number of sources exist in various jurisdiction.

For the purposes of this report, "emission standards" means regulations, guidelines, codes of practice or other similar control instruments, which specify limitations on the emission rates or concentrations of contaminants released to air from stationary and mobile anthropogenic sources.

Emission standards are usually based on available air pollution control technologies. However, environmental agencies do not specifically mandate actual technologies, but allow proponents to select their own process, system, equipment and manufacturers, provided that the appropriate emission rate is achieved. This usually provides proponents and others with a range of technological options. It also provides incentives to select the most cost-effective option, and to research, develop and demonstrate other technologies that will meet or be lower than the maximum allowable emission standards.

Technology-based emission standards are often used in conjunction with ambient air quality objectives, so that the most stringent limitation will apply to an emission source. While technology-based standards establish minimum control levels, ambient air quality standards must also be maintained. Evidence of probable attainment of satisfactory air quality can be obtained by using dispersion modelling. In some very contaminated air sheds, applying minimum technology-based emission limits may not be sufficient, and a new emission source may not be permitted in that area.

Environment Ontario is now developing and using this regulatory approach in their Clean Air Program (8). Two technology based control levels may be used: -

Lowest Achievable Emission Rate (LAER)

This emission rate can be achieved by an emission control system which is available anywhere in the world, regardless of cost. A new technology of equivalent performance can be used, of course.

Best Available Technology Economically Achievable (BATEA)

This emission rate can be achieved by the best control technology generally available, taking into consideration reasonable economic or other factors. A BATEA evaluation usually examines alternative control measures of various levels of stringencies and considers the incremental economic and other aspects of each alternative (e.g. energy use).

In this two-level system, LAER is applied to very highly toxic contaminants, and moderately toxic contaminants that are of relatively high concern with respect to persistence, bioaccumulation and transport. (Examples of these contaminants are dioxins, acrylonitrile, benzo(a)pyrene, lead and cadmium. BATEA is applied to other air contaminants, that are less toxic, but are of environmental and health concern. (Examples of these contaminants are sulphur dioxide (SO_2) and nitrogen oxides (NO_X)).

Tables 2-1, 2-2, 2-3, and 2-4 summarize the existence of emission standards for various sources of NO_X and VOC. Further details are provided in the Work Sub-Group reports and related literature.

Although the information presented should be confirmed with the responsible regulatory authorities, Tables 2 do provide a preliminary overview of the existence of emission standards for various NOx and VOC sources, in Canada and other countries. (Blanks in the tables indicate that no known emission standards existed for that source or jurisdiction.)

Table 2.1.1a - Status of Emissions Standards - Canada
New* Mobile Sources - NOx, VOC

Source	CAN	OTHER		NOTES
■ Gasoline Fuel	R (1)		(1)	Environment Canada Lead in Gasoline-Lower Level announced Can. Gazette Part 1, July 15, 1989.
■ Diesel Fuel	R (2)		(2)	Environment Canada Sulphur in Diesel limitation - Expected announcement Can. Gazette, Part 1, Sept, 1990.
■ Light Duty Gasoline Vehicle (LDGV)	R (3)		(3)	Transport Canada-Current standards in effect Sept 1, 1987.
■ Heavy Duty Vehicles (HDV)	R (4)		(4)	Transport Canada-Current standards in effect Dec 1, 1988.
■ Heavy Duty Diesel Vehicle (HDDV)	R (5)		(5)	Transport Canada-more stringent regulation contingent on Environment Canada sulphur in diesel limits (2). Sulphur in diesel affects particulate control systems.
■ Off-Road Diesel Equip. (Farm, Construction etc.)	(6)		(6)	Legislative authority required to regulate.
■ Miscellaneous Gasoline Engines	(6)		(6)	
■ Stationary Reciprocating Engines-Diesel	(7)	(7)	(7)	Legislative authority required. Some provinces may regulate.
■ Natural Gas Turbines	(8)	(8)	(8)	Legislative authority required. Some provinces provinces may regulate, e.g. Alberta.
■ Rail, Marine Aircraft	(9)		(9)	Legislative authority required to regulate. Transport Canada does not have authority now to impose International Civil Aircraft Organization (ICAO) standards.

*See Table 2.1.1b for In-Use Vehicle Standards

LEGEND

R - Regulation

( ) - Note Number

Table 2.1.1b - Status of Emission Standards - Canada
In-Use Vehicles

Province	NFLD	PEI	NS	NB	QUE	ONT	MAN	SASK	ALTA	BC	YUK	NWT
EMISSION CONTROL EQUIPMENT												
Anit-Tampering Legislation	Y	N	N	P	Y	Y	N	N	N	Y	I	I
Possible Date				1990								
Idle Emissions Specifications	N	N	N	N	N	Y	N	N	N	##	N	N
Aftermarket Catalyst Legislation	N	N	N	I	N	Y	N	N	N	I	N	N
Enforcement Program												
Annual I/M	N	N	N	I	N	I#	N	N	I	P	N	N
Spot Check	N	N	N		N	Y	N	N	N	P	N	N
On Resale	N	N	N		N	P*	N	N	N	I	N	N
Possible Date			?	?		#93/95 *90				90/91		
Anti-Misfuelling Legislation	Y	N	I	I	N	Y	N	N	N	N	N	N
INLET RESTRICTOR												
Legislation	Y	N	N	P	Y	Y	N	N	N	N	N	N
Enforcement Program	N	N	N	I	N	S	N	N	N	I	N	N
NOZZLE Tampering												
Legislation	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Enforcement Program	S	S	Y	Y	Y	Y	N	L	N	L	N	N
VISIBLE OR SMOKE Emissions Legislation												
LDV	N	N	?	Y	Y	Y	Y	Y	N	N	?	N
HDV	N	N	N	Y	Y	Y	Y	Y	N	Y	N	N
Enforcement Program	N	N	N	N	L	L	?	**	N	L	N	N
SAFETY CHECK												
Existing Leg.	Y	Y	Y	Y	Y	Y	Y	?	I	(C)	Y	N
Enforcement Program												
On Resale			N		N	Y	N	N	N	N	N	N
Spot Checks					Y	Y	Y	N	N	(C)	(C)	N
Annual	Y	Y	Y	Y	N	N	N	***	I	(C)	N	L
GASOLINE QUALITY												
CGSB Standards	N	Y	Y	N	N	Y	N	F	Y	F	F	N
Other	I				Y		Y			N		Y
RVP Standards	I		I	P		Y		F		I		

LEGEND:

Y - Yes
I/M - Inspection Maintenance

Y = Yes
P = Planned
? = Unknown at this time
R = Regulation
N = No
S = Spot Checks
I = Investigating
L = Limited Program
(C) = Commercial Vehicle only
( ) = Note Number

** = has never been applied to mobile sources
*** = program discontinued in 1984
F = Industry Reported to Follow Canadian Government Standards Board
= No idle specs., but list federal test standards in legislation.

Table 2.1.2 - Status of Emission Standards - International Mobile Sources - NOx, VOC

Source	USA	CALIF.	OTHER	NOTES	
■ Gasoline Fuel	R	R		(1)	Regulations of the U.S. Environmental Protection Agency (EPA) will influence all vehicles manufactured in USA and Canada. Generally California standards are move stringent than EPA standards.
■ Diesel Fuel	R(5)			(2)	Generally, European vehicle emissions standards are currently less stringent than North American requirements.
■ Light Duty gasoline Vehicles (LDGV)	R(1)	R(1)		(3)	Technical and economic feasibility studies are being conducted by California and EPA. Regulations for off-road diesels and other sources are expected.
■ Heavy Duty Gasoline Vehicles (HDGV)	R(1)	R(1)		(4)	The International Civil Aircraft Organization (ICAO) has noise and emission standards. Only the noise standards have been adopted as regulations by Canada.
■ Off-Road Diesel Equipment	D(3)	D(3)			
■ Stationary Reciprocating Engines-Diesel					
■ Gas Turbines					
■ Rail, Marine Aircraft				(5)	EPA limits diesel sulphur in fuel to 0.05percent by 1994.

LEGEND:

R - Regulation, D-Regulation being developed
G - Guideline

Table 2.2.1 - Status of Emission Standards - Canada Stationary Sources - NOx

Sources	CAN	NFLD	PEI	NS	NB	QUE	ONT	MAN	SASK	ALTA	BC	NWT	YUK
■ Electric Utility Boiler	G(1)	P(2)	P	P	P	R,P	R,C,P (3)	P	G,P (4)	G,P (4)	R,P		
■ Industrial Boilers	R(5)	P	P	P	P	P	P	P	P	P	P,G (6)		
■ Combustion Turbines (7)						P	P	P	P	P	P		

LEGEND:

R - Regulation; G - Guideline; P - Site-specific permit; C - Total emission cap

Table 2.2.1 - Notes

(1) Environment Canada issued Guidelines (1981) for NOx, SO_2 and particulates. It is expected that NOx emission levels will be lowered, to reflect performance of current technologies.

(2) Most provinces have site-specific permitting systems, but many do not have uniform or minimum emission standards.

(3) Ontario has imposed "caps" on utility SO_2 and NOx emissions.

(4) Alberta and Saskatchewan have regulatory requirements for new utility boilers which are similar to Environment Canada guidelines (1).

(5) Regulation for boilers at federal facilities (expected summer 1990), are being developed under the Canadian Environmental Protection Act, Part IV.

(6) British Columbia is developing emission guidelines for industrial boilers which will be applied to site-specific permits. (expected summer 1990).

(7) Some gas turbine manufacturers are voluntarily adopting California emission standards.

Table 2.2.2 - Status of Emission Standards - International (0) Stationary Sources - NOx

Sources	USA	CALIF.	EUR	FRG	JAP	NOTES
■ Electric Utility Boilers	R(1)	R(2)	R(3)	R(4)	R(5),P	(1) (2)
■ Industrial Boiler	R(6)	R	R(3)	R(4)	R(5)P,	
■ Combustion Turbines	R	(6)				

LEGEND:

R - Regulation, P - Site-specific permit

Table 2.2.2 - Notes

(1) US Environmental Protection Agency promulgated New Source Performance Standards (NSPS), (1977), for NOx, SO_2 and particulates. Under proposed amendments to the Clear Air Act, proposed in Summer 1989, reductions of SO_2 and NOx emissions from existing sources, are expected.

(2) California South Coast Air Quality regulations, in effect, prevent the use of coal or oil in utility boilers.

(3) The European Community Ordinance for Large Furnaces, applies to all boilers over 100 MW (thermal).

(4)(5) Emissions standards in Southern California, the Federal Republic of Germany (FRG) and Japan are the world's, most stringent.

(6) Some gas turbine manufacturers are voluntarily adopting California emission standards.

Table 2.3.1 - Status of Emission Standards - Canada Large Stationary Sources - VOC

Sources	CAN	NFLD	PEI	NS	NB	QUE	ONT	MAN	SASK	ALTA	BC	NWT	YUK	MUC
■ Crude Oil Production - Storage											G			
■ Petroleum - Storage - Equip Leak - Process					R(1)	R(2)	G			P(6) P(7)	G(8)			B(2)(4) B(3)
■ Gasoline Distribution - Storage - Serv. Stat. Deliveries - Vehicles Refuelling - Volatility Reduction					R(1) T	R(2) R	R(5)							B(2)(4) B(4)
■ Petrochemical & Organic Chem. - Storage - Equip Leak						R(2)	G			P(6), P(7)				B(2)(4)
■ Plastic Processing														
■ Pulp & Paper														
■ Wood Transformation														

LEGEND:

R - Regulation, G - Guideline, B - By-Law Montreal Urban Community, P - Site Specific Permit, T-Proposed Regulation

Table 2.3.1 - Notes

(1) NB regulation applies to tanks with capacity greater than 23.80 m^3 for liquids with true vapour pressure (TVP) greater than 10.3 kPa.

(2) Quebec and Montreal requirements apply to new tanks with capacity greater than 250 m^3 and TVP greater than 10kPa, and to existing tanks greater than 1500m^3 (or flow-through greater than 4,500m^3 for refineries) and TVP greater than 10kPa.

(3) Requires 90% reduction of asphalt Oxidation Emissions.

(4) Requires submerged loading for tank greater than 5m^3, storing Organic liquids.

(5) Gasoline volatility limited to 72kPa during summer 1989.

(6) In general applies to tanks over 15 m. diameter and with TVP greater than 21kPa.

(7) Requires an approved leak detection and repair program.

(8) Applies to petroleum product tanks having a capacity greater than 245 m^3 when the liquid TVP is greater than 10.5kPa.

Table 2.3.2 - Status of Emission Standards - International Large Stationary Sources - VOC (7)

Sources	USA	CO	GA	IA	ME	MD	NJ	TX	WA	CA
■ Crude Oil Production										
■ Petroleum Refining										
- Storage	C(1)N	R	R	R	R	R	R	R(P)	R	R
- Equip Leak	C,N	R	R	R		R		R(P)	R	R
- Process	C,(2)N	R	R					R(P)	R	R
■ Others	C(3)N(P)	R	R					R(P)	R	R
■ Gasoline Distribution										
- Storage	C(4),N	R	R	R	R	R	R	R(P)	R	R
- Serv. Stat. Deliveries	C		R		R	R	R	R(P)	R	R
- Vehicle Refuelling	C							R(P)		R
- Volatility Reduction	R(5)				R(6)	R(P)(6)	R(6)	R(7)		R(6)
■ Organic Chemical Industry	C(1)									
- Storage	N	R	R	R		R	R	R(P)		R
- Equip Leak	C,N			R				R(P)		R
- Process	N							R(P)		
■ Natural Gas Production										
Equip. Leak	C,N			R				R(P)		R
■ Rubber Products	C,N		R							R
■ Pharma-ceutical	C,N		R					R(P)		

LEGEND:

C - Control Technique Guidelines (CTG)
N - New Source Performance Standard (NSPS)
R - Regulations
(P) - Proposed

State regulations when not otherwise specified, are roughly equivalent to U.S. EPA Guidelines and Standards.

Table 2.3.2 - Notes

(1) Some provisions for tanks > 151 m^3 with TVP $\geq$ 3.5 kPa, and others for tanks 75m^3 with TVP $\geq$ 27.6kPa.

(2) Control Technique Guidelines (CTG) for Vacuum producing systems.

(3) CTG for process unit turnaround and Waste Water Systems NSPS proposed for Waste Water Systems.

(4) CTG bulk plants and terminals, NSPS for Bulk terminals.

(5) 9.0 PSI to 10.5 PSI (62 to 72 kPa)depending on regions.

(6) Reduction to 9 PSI (62kPa) for May to September.

(7) European standards were being complied at time of report printing.

Table 2.4 - Status of Emissions Standards - Canada International Miscellaneous Sources - VOC

Source	CAN	OTHER	NOTES
■ Paint Application			(1) General: Few Standards exist for the control of VOC's from the sources listed. (See 4.4)
■ Glue and Adhesive Application			California South Coast Air Management Board is developing stringent regulatory requirements.
■ Printing Inks			Other jurisdictions in the USA with ozone excedences are are expected to develop control programs, and will be influenced by the US EPA proposed Clean Air Act Amendments.
■ Industrial/ Commercial degreasing			Initiatives are also being developed in Europe to control VOC sources.
■ Dry Cleaning			
■ Consumer Products - Automobile - Household - Personal Use			
■ Pest Control			
■ General Solvent Use			
■ Misc. Industries			

3. CONTROL TECHNOLOGIES

A summary of the status, effectiveness and estimated costs for various NO_X and VOC control technologies, is presented in Tables 3-1, 3-2, 3-3 and 3-4. Further descriptions and details of these control technologies are presented in the four Work Sub-Group reports (9.1, 9.2, 9.3 and 9.4).

Figures 3-1 and 3-2 shows estimates of reductions in NO_X and VOC from all identified sources if emission control technologies are applied to new and existing sources.

It is noted, however, that these are order of magnitude estimates only, and do not take into account all the technical, environmental, economic, social and other implications of applying various control technologies.

Some reviewers of the draft report commented that the type of information presented in Tables 3-1, 3-2, 3-3, 3-4, was not consistent. The data presented were from the four Sub-Groups. It is recognized that more uniform and comprehensive data are preferable and may be developed later in the CCME-NO_X/VOC Management Program.

Table 3-1. Effectiveness of Emission Control Technologies

- Mobile Sources

SOURCE/CONTROL TECHNOLOGY	STATUS	EMISSION REDUCTION POTENTIAL (%)			ESTIMATED UNIT COST(1)
		NO_x	VOC	CO_2	
▪ Light Duty Gasoline Vehicles (LDGV)					
- Improved catalysts and air fuel mixture control, exhaust gas recirculation	CE	90 64kt	90+ -3 (2) 16kt (3)		
- Better Evaporation Systems	R	-	?		
- On Board Refuelling Emission Control	R	-	?		
- Lower Gasoline RVP	C	-	?		
▪ Heavy Duty Gasoline Vehicles (HDGV) - same as LDGV	C	50	0	0-4	
▪ On-Road Diesel Engines (ORDE)	CE	45-55	38	0-4	
- Turbo charging, aftercooling, better injection, exhaust gas recirc.					
▪ Off-Road Diesel Engines (Construction, Agriculture) (Forestry, Mining)	R	TBD		0-4	
▪ Other Diesel Engines (Locomotives, etc.)	R	TBD			

LEGEND:

R - Research and Development, Pilot
D - Demonstrated Full Scale
C - Commercial in Canada
CE - Commercial in USA, Europe or Japan
TBD - To be determined
(1) Being determined at time of report printing.
(2) Emission reduction%from uncontrolled case.
(3) Emission reduction (ktonnes) from current Canadian standards to California standards.

Note: Emission reduction unit costs will change from those shown in CCME July 89 report. MOBILE IV emission factors will be used.

Table 3-2. Effectiveness of Emission Control Technologies

STATIONARY SOURCES - NO_X, OTHER

SOURCE/CONTROL TECHNOLOGY	STATUS	EMISSION REDUCTION POTENTIAL (%)	ESTIMATED UNIT COST
		NO_X	1988$/Tonne NO_X (1988$/kw)
■ Electric Utility Boilers			
- Combustion Controls (1)	C	5-80+	30-95
- Flue Gas Controls (SCR, NSCR) (2)	CE	70-90	630-1500
- Fluidized Red Combustion (FBC) (3)	D	50-80	(1500+)
- Integrated Gasification Combined Cycle (IGCC) (3)	D/R	90-95+	(1200-2000)
■ Industrial Boilers			
- Combustion Controls	C	5-80+	50-95
- Flue Gas Controls	CE	70-90+	630-1500
■ Gas Turbines			
- Steam Injection	C	70+	
- Water Injection	C	70+	
- Catalytic Exhaust Gas Treatment	CE	90+	

LEGEND:

R - Research, D - Demonstrated, C - Commercial in Canada,
CE - Commercial USA Europe/Japan.

NOTES:

(1) "Combustion Controls" includes fuel and air mixing techniques to reduce NO_X emissions, such as low-NO_X burners, low excess air, overfire air, air and fuel staging etc. These modifications to existing boilers may in some cases, increase unburned hydrocarbon (VOC) emissions. These modifications may also yield small improvements in energy efficiency.

(2) "Flue Gas Controls" includes post-combustion techniques to reduce NO_X emissions, such as Selective Catalytic Reduction (SCR). Selecting Catalytic Reduction (SCR) will result in emission of ammonia.

(3) Fluidized Bed Combustion (FBC) and Integrated Gasification Combined Cycle (IGCC) will also reduce SO_2. IGCC will yield better cycle efficiency than conventional plants.

Table 3-3. Effectiveness of Emission Control Technologies

LARGE STATIONARY SOURCES - VOC

Source Controlled	Forecasted Emission 2005 ktonnes	VOC Reduction Potential(2005) %	ktonnes	Costs (1987$) Per tonne VOC	Annual ($ X 10^6/year)
■ Crude Oil Production and Receipt					
Fugitive Emissions	27.0	70	18.9	1000	18.9
Transfer Emissions	1.3	75	1.0	?	?
Subtotal	28.3	-	19.9	-	18.9+
■ Petroleum Refining					
Fugitive Emissions	28.8	80	23	412	9.5
Storage Emissions	20.5	89	18.2	231(1)	4.2
Subtotal	49.3	-	41.2	-	13.7
■ Gasoline Distribution and Marketing					
Storage and Transfer at Depots	32.6	86(1)	28.1	103(1)	2.9
Delivery to service Station	33.3	84	28.0	170	4.8
Vehicle Refuelling	46.1	80	36.9	3000	110.7
Gasoline Volatility	12.4	100	12.4	1000	12.4
Subtotal	124.4	-	105.4	-	145.7
■ Organic Chemical Manufacturing					
Process Emissions	191.4(2)	94	178.5	329	58.7
Fugitive Emissions	12.4	56	7.0	1535	11
Subtotal	204.3	-	185.5	-	69.7
■ Plastic Processing					
- Process Emissions	28.0		?		?
■ Pulp and Paper					
- Sulphate Process Emissions	24.9		?		?
■ Wood Transformation					
- Wood Waste Burning	54.0		?		?
TOTAL	513.2		352.0		248.0

NOTES:

(1) Average for a series of measures.
(2) Estimate of "uncontrolled" emissions Actual emissions may be significantly lower.

Table 3-4. Effectiveness of Emission Control Technologies

MISCELLANEOUS SOURCES - VOC *

Product	Possible VOC Reduction Strategy	Estimated Annual Emission (tonnes)	Possible Annual Reduction (tonnes)
■ Paint Application	- 50% ext.oil base paints reduced to 0.25 kg/L emission limit - 50% primers reduced to 0.25 kg/L emission limit - substitution of water-base for 75% of interior oil-base - substitution of 0.2kg/L solvents for 25% of thinners - Add-On controls (25% use level)	188,000	2,030 (trade)[1] 4,960 (all)[2] 3,210 (trade) 7,830 (all) 5,350 (trade) 13,050 (all) 4,070 (trade) 9,940 (all) 24,700 (all
■ Application of Glues & Adhesives	- use of water base and/or low solvent adhesives	35,000	8,750
■ Printing Inks	- 90% of industry with add-on controls - combined reduction efficiency of 75 - 90% - 50% of flexography process with reduction efficiencies of 90%	20,010	13,700 4,600
■ Industrial/ Commercial degreasing	- add on controls to reduce VOC emission process changes	17,000	5,100 3,400
■ Dry Cleaning	- add on controls - process changes	14,000	2,000 1,500
■ Consumer Products			
- Automobile products	- ban windshield wash 6 months/yr[3] - 50% reduction in VOC's from propellants	37,000	13,950 220
- Household products	- banning of reactive VOCs from propellants - 20% reduction in solvent of products	12,000	910 4,970
- Personal use products	- banning of reactive VOCs for propellants - 20% reduction in solvent content of products	22,000	1,400 4,710
- Aerosols		11,000	
■ Pest control products	- reduction of solvent content - improved transfer efficiency - product substitution	11,000	TBD
■ General solvent use	- lower vapour pressure solvents - solvent recycling	Not available	
■ Miscellaneous Industries	135,000		
Estimated Total		502,000	

NOTES:

* Table revised per data provided 90/01/05.

(1) Including trade sales only.
(2) Including industrial and trade sales.
(3) Assuming all methanol used in windshield washer fluid.

TBD To be determined.

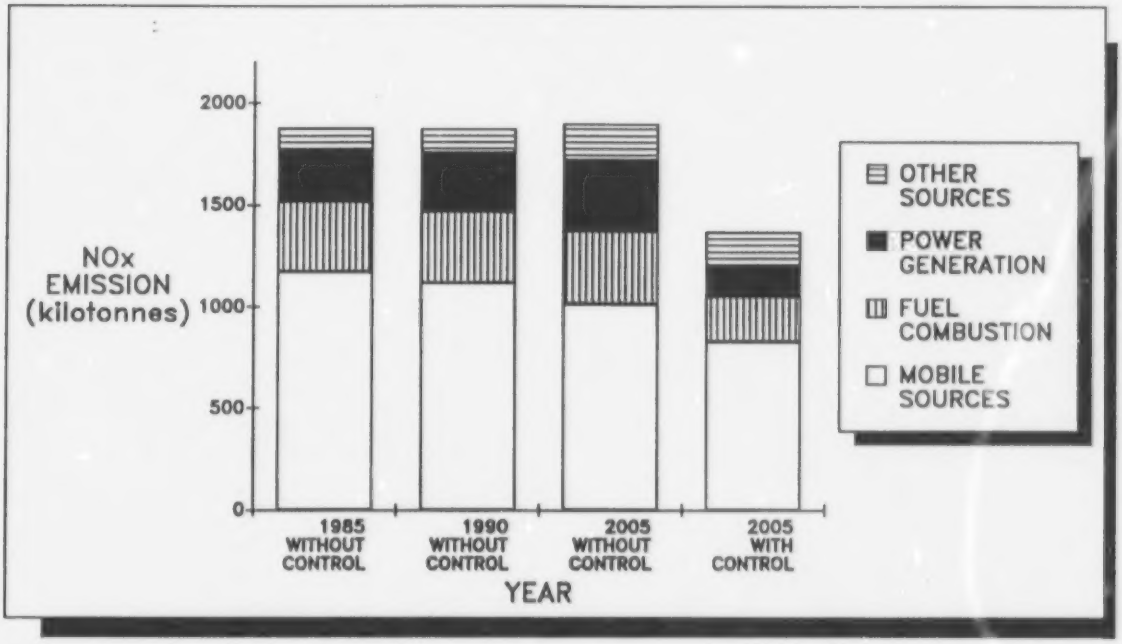

Figure 3-1. Total NO_X Emissions Without and With Controls (2,3)

	WITHOUT CONTROLS 1985	1990	2005	CONTROLS 2005
Mobile Sources	1178	1123	1021	829
Fuel Combustion	346	350	357	222
Power Generation	248	288	352	143
Other Sources	113	117	174	174
Total	1885	1878	1904	1368

NOTES: (Figure 3-1)

(1) Source: Draft Report to CCME Federal/Provincial Long Range Transport of Air Pollutants Steering Committee, on Status of National Inventory of NO_X/VOC, December, 1989, Revised February 2, 1990.

(2) Data subject to revisions.

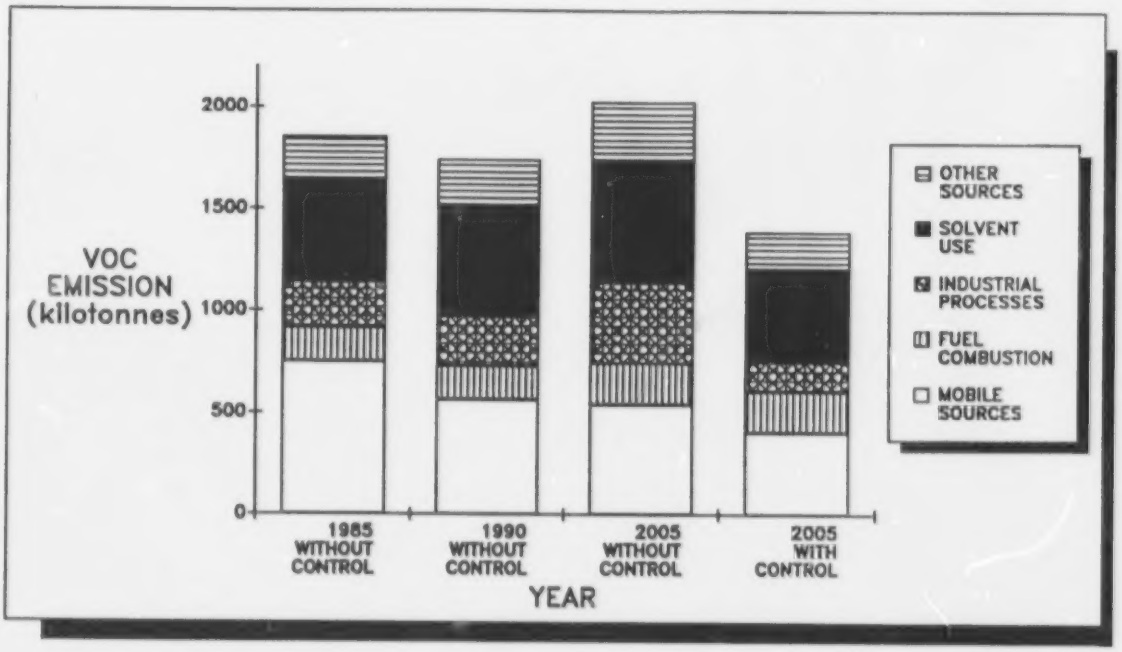

Figure 3-2. Total VOC Emissions Without and With Controls (2)

	WITHOUT CONTROLS 1985	1990	2005	CONTROLS 2005
Mobile Sources	749	574	561	407
Fuel Combustion	164	164	203	203
Industrial Processes	224	239	394	147
Miscellaneous	215	224	286	180
Solvent Use	502	550	603	452
Total	1854	1751	2047	1389

NOTES: (Figure 3-2)

(1) Source: Draft Report to CCME LRTAP Steering Committee, on Status of National Inventory of NO_x/VOC, December, 1989, Revised February 2, 1990.

(2) Data subject to revisions.

4. CONCLUSIONS AND RECOMMENDATIONS

Various conclusions and recommendations from the four control technology Sub-Groups, are summarized below:

4.1 Mobile Sources, NO_X/VOC Sub-Group 6.1

The following summarizes the NOx/VOC Mobile Sources Control Technology Report and makes recommendations for elements that should be included in a National NOx/VOC Control Plan.

On-Road Vehicles

Regulatory authority exists for all new on-road (and some off-road) vehicles under the Motor Vehicles Safety Act (MVSA). A Transport Canada and Environment Canada plan has started the process to adopt stricter emission regulations for the vehicles now regulated under the MVSA, and for the fuels they use.

The MVSA should be modified to allow for greater regulatory flexibility if Canada wishes to adopt technology-forcing regulations in parallel to the U.S.A or California. Recall provisions should be added to the MVSA. Uniform regulations on warranties for emission control systems and components should be adopted by the provinces or they should be included in the MVSA.

A mechanism should be set up to allow manufacturers to have access to provincial registration information, so that they could contact all owners of recalled vehicles. (Manufacturers often lose track of owners of the vehicles they have sold because the original owner moves before the vehicle is resold). This would increase the effectiveness of recalls.

It is recommended that the federal government change its labelling requirements to include bar codes describing the vehicle and its emission control system. This would help agencies that run Inspection and Maintenance (I&M) programs.

A formal mechanism to coordinate I&M activities among the provinces and the federal government should be set up.

"Canada cannot adopt a 0.10 grams per brake horsepower hour particulate standard like those to take effect in the U.S. in 1994 without promulgating a similar regulation for reducing diesel fuel sulphur levels. If sulphur levels in diesel fuel destined for use in trucks and buses is not at or below 0.05% sulphur content by weight, manufacturers will probably not supply trucks or buses with catalytic after treatment devices. (It is noted that sulphur in fuel affects particulate control systems, and not NO_X emissions).

The Canadian Environmental Protection Act (CEPA) may have to be amended to allow regulation of fuel volatility if it is decided that the federal government should enact volatility limits. It may be more appropriate to regulate volatility at the wholesale level than at retail sale as is now done in those provinces that have regulations on fuel quality.

All provinces should enact anti-tampering legislation. Uniform enforcement program goals for the performance of the in-use fleet should be set with a link to the ambient air quality.

The provinces could request that the federal government enforce requirements for the performance of aftermarket replacement catalysts if they adopt uniform replacement catalyst requirements. (The U.S. Environmental Protction Agency (EPA) and California already have a catalyst approval program).

Off-Road Vehicles

The engine size, duty cycle and hours of operation of off-road vehicles are different from on-road vehicles and cover a greater range. Each category (mobile equipment, stationary engines, air, rail and miscellaneous) is smaller than either the light duty and heavy duty vehicles. Due to the international nature of industries supplying engines and equipment for off-road mobile sources, the size of each segment and its contribution to air pollution, it is not practical for Canada to develop its own set of requirements. Regulations for off-road engines and equipment should be based on the adoption of U.S. or international standards for each source.

The U.S. Clean Air Act will probably require EPA to regulate off-road sources. California already has the authority and has begun the steps needed to regulate all mobile sources.

The NOx/VOC plan must address the need to develop regulatory authority for off-road mobiles sources and internal combustion (IC) engines in order to be able to adapt regulations for off-road sources, should this be necessary. There are many questions to be answered. For example, it is not clear where and how stationary engines should be regulated. National Standards may not be able to adequately address the impact that a large fixed source can have on a particular site. Federal Standards could be used certify engine types but could not specify stack heights or assess the benefits of one engine type over another at a particular site, as can be done with permits. Whoever is chosen as the potential regulator, should also be responsible for developing the data needed to evaluate the need for and benefit of further regulation.

Most emission data for off-road sources is derived form fuel used and antiquated emission factors found in US EPA report AP-42. While this may be adequate for an overall yearly inventory it does not allow a reasonable estimate for the cost and benefits of regulation. The present information on: the number, spacial distribution and use of off-road equipment is non-existent or inadequate for most off-road sources. There is a need to identify the number and usage rates for all mobile sources and IC engines in order to be able to use the information on emission rates that will become available as a result of studies in support of regulations in the U.S.

4.2 Major Stationary Sources - NO_X Sub-Group 6.2

Conclusions

1. There are proven and commercially available technologies for reducing NOx emissions from commercial, industrial and utility boilers as well as for combustion turbines. Major advances in NO_X control technologies have been developed, demonstrated and used in recent years in Japan, Federal Republic of Germany and California. However, some of the most promising techniques require further research, development and demonstration, for some Canadian fuels under Canadian conditions.

2. Reduction levels which can be achieved depend on the fuel being burned and the size and type of unit.

   - In general, industrial and commercial sized gas-fired boilers should be able to achieve emission levels of 85 ng/Joule or less on existing units and lower than 30 ng/Joule on new units employing current advanced control technologies.

   - Industrial and commercial sized heavy oil fired boilers can be controlled to below 150 ng/Joules on existing units and in the range of 90 ng/Joule on new units, again by using current advanced control technologies.

   - Large coal fired boilers are very diverse in their design configuration, and fuel characteristics are very variable. As a results, the NO_X reductions achievable may vary, especially on retrofit applications. In general, most existing units can be reduced from 250 ng/Joule NO_X emission levels to a range of 130 to 190 ng/Joule . (The lower levels typically are achieved by simultaneously using more than one reduction technique and by applying techniques and by applying techniques such as advanced low NO_X burners, air staging and improved combustion controls). New units, designed to take full advantage of recent NO_X reduction combustion measures should be able to achieve emission levels below 100 ng/Joule while ensuring acceptable combustion and levels of performance.

   - Combustion turbines can be controlled to NO_X emission rates of below 75 ng/Joule on existing units and for new units, levels in the range of 20 ng/Joule have been reported by manufacturers.

The reductions described above are achievable without resorting to flue gas treatment such as Selective Catalytic Reduction or advanced fuel burning systems such or Coal Gasification Combined Cycle. If these are employed, most combustion equipment can be controlled to NO_X levels below 30 ng/Joule.

3. There is a requirement to identify the best emerging control options and target them for development and demonstration. It is noted that retrofitting existing boilers to achieve low NO_X emissions, may present a number of difficulties.

Recommendations

1. Further work is recommended on several technologies, particularly Fuel Air Mixing/Low NOx combustion techniques such as Fuel/Air Staging, Flue Gas Recirculation and advanced burners. Demonstration of promising technologies is also encouraged, including Integrated Coal Gasification Combined Cycle, Slagging Combustors more advanced Fluidized Bed Combustors, Advanced Sorbent Urea Injection and Selective Catalytic Reduction.

   Research should be monitored on an ongoing basis on promising techniques such as Pressurized Fluidized Bed Combustion, and advanced flue gas treatment techniques which may allow joint reduction of SO_2 and NOx emissions.

2. The plan should establish emission limits to be achieved or emission source categories by class of equipment rather than specifying a particular technological fix as "best available." The plan should also allow for regional flexibility in meeting emission limits recognizing that in some areas VOC are a more serious problem than NO_X.

3. The plan author should not overlook the contribution that can be made to NOx control by implementing economic demand-side measures.

4. The plan development process should allow sufficient time for full consultations and should consider cross-linkages with other environmental problems such as acid rain or global warming.

5. It was also recommended by Canadian Electrical Association representatives that:

   Controls should only be enforced if there is a regional problem (Nova Scotia Power).

The control of NO_X and/or VOC should be addressed on a "regional basis" and be supported with adequate "emission and ambient measurements," and that controlling NO_X as a "national policy" may not be a prudent solution (Alberta Power Ltd.)

6. It was suggested by an Energy, Mines and Resource representative that:

6.1 Under a cost/effective scenario:

a) existing units which are only slightly above a target NO_X limit be given a variance.

b) units that are uneconomic to retrofit be "grandfathered" for a certain time to allow replacement with a combustion system compatible with the process application.

6.2 Given the scarcity of present knowledge and experience with retrofitting low NO_X burners in Canada, NO_X emission limits should be reduced in steps over a 5 to 10 year period to reflect levels consistently attainable in practice with different fuels and burner concepts in various generic furnace configurations.

6.3 The NO_X control strategy recommended above will avoid wasteful mandatory retrofitting of units that will provided little or no environmental benefit. Systematic reductions in NO_X levels based on operating experience with burner designs will be cost effective and will be widely supported by users. A progressive reduction in NO_X emission limits will encourage a steady movement toward a desired target, instead of a strong reaction against making any technology improvements until the desired target can be met with confidence.

4.3 Large Stationary Sources - VOC, Sub-Group 6.3

The following are the major conclusions and recommendations from the Large Stationary Sources Work Sub-Group.

Conclusion

The coverage and accuracy of the current VOC inventory is not totally adequate. There is some work underway to improve the emission data for the petroleum refining sector, the crude oil production and receipt sector, the organic chemical sector and the gasoline marketing and distribution sector. The emission inventory is likely to be substantially changed for the first three sectors. Some new data should be available in March 1990.

Recommendation

It is recommended that the new emission data be incorporated and taken into consideration for the Management Plan, as it becomes available.

Conclusion

The emission inventory for the plastics processing sector and, for the pulp and paper and wood transformation sectors, are to some extent qestionable. Other potential emitters described in chapter 4 of the Sub-Group report, (such as the natural gas processing industry), are not included in the current inventory.

Recommendation

It is recommended that emissions surveys be undertaken for the pulp and paper, wood transformation, natural gas processing and other sources of similar size which not currently inventoried.

Conclusion

It has been brought to the attention of the Work Sub-Group that the labour productivity in Canada is lower than in the U.S. for numerous reasons. (e.g. climatic conditions). Capital costs to install control technologies would also be higher in Canada because the need for weatherproofing (to allow winter operation) of the equipment.

These factors have not been taken into account in the cost estimates and could result in substantially higher costs for certain applications.

Recommendation

It is recommended that costs and cost effectiveness estimates presented in this report be reviewed by independent experts to verify their accuracy.

Conclusion

The potential reductions presented for the crude oil production, petroleum refining, organic chemical manufacturing and gasoline distribution and marketing sectors seem to be the maximum potential reductions. However, the costs presented were generally calculated for average circumstances.

Recommendation

Further studies are recommended to establish incremental costs per unit of reduction for each control measure presented, and to identify threshold conditions where the incremental costs becomes prohibitive with respect of the reduction achieved. A "cost effectiveness" scenario could then better identify reductions likely to be achieved at a given cost.

(A good example of this is the recovery of service station delivery emissions ("stage 1 control") where a minimum size or throughput under which service stations would be exempted has to be established).

Comments

A representative from Turbo Resources Ltd. commented:

In the recommendation "to establish incremental costs per unit of reduction" there are really two issues. The first issue is the question of non linearity of benefit for all emitters i.e. the fact that 20% reduction of VOC from a source may not cost 1/4 of an 80% reduction. This would create one type of cost effectiveness scenario. The second issue is economics of scale, the issue that is presented in the example in the second paragraph. Again a "cost effectiveness" scenario can be developed but is a quite different analysis from the other "cost effectiveness" scenario.

Conclusion

The accuracy of the emission forecasts have been questioned by industry representatives.

Recommendation

Parameters used to generate emission forecasts need to be reviewed with industrial sectors and revised if necessary.

Conclusion

Controls for the plastics processing, pulp and paper and wood transformation sectors, could not be identified.

Recommendation

It is recommended that the availability of emission controls for the plastics processing, pulp and paper and wood transformation sectors, be further investigated.

Conclusion

This report addresses reductions and costs with a national perspective.

Recommendation

It is recommended that provincial or regional reductions and costs be established more accurately.

Conclusion

The Working Sub-Group realizes that all these supplementary studies will take time. It also understands that CCME has identified the current ozone levels in certain parts of the country as a problem requiring immediate action. A means of reconciliating these two realities has to be found.

4.4 Product Substitution and Miscellaneous Sources - VOC - Sub-Group 6.4

Status Report - Activities To December 15, 1989

This particular sub-group is concerned with a number of dissimilar industrial and commercial activities - not all of which have been completely investigated or even defined yet. In addition to industrial emission control technologies and process measures, consumer product emission reductions and substitution and reformulation of products used by both the consumer and industry are also of interest. Since it is interested in "miscellaneous sources", this group is, theoretically, also interested in any VOC emissions not included in other working group activities as well.

Few of the industrial sectors of initial interest to the group, were represented in the workshop sessions. Consequently, representatives who had not participated previously, had to be found for the group. While group members were being sought, a consultant was contracted in mid-October to provide a reference document on emissions, emission reduction technologies, and reformulation and substitution options for the group.

Terms of reference for the newly formed group, an explanation of the contractors' work, a group membership list and other related information were distributed on October 27 and November 27, 1989.

Due to the very different interests the report was distributed on December 6. Members were asked to review the report and provide comments, corrections, and recommendations before December 15th if possible, and by December 21 at the latest.

A noteworthy addition to the information on solvents use in Canada has been provided by one of the working group members. It is a table of solvent usage in Canada by specific solvent type (e.g. xylene, toluene,...) and specific end use (e.g. paints & coatings, degreasing,...). Specific estimates of this kind have not previously been available. While it cannot be assumed that all of the solvents used in every sector will eventually become VOC emissions, this data does provide a check on existing emission estimates and does permit consideration of priorities setting for reduction activities based on solvent reactivities (high reactivity vs low, and ozone formation potential). Some, but not all, of this information has been utilized in the consultants report and some discrepancies still remain to be resolved.

Comments received to date indicate the report provides some significant improvements in VOC emission and potential reduction estimates, identifies some additional emission sources, and indicates where significant information improvements are required for emission reduction decisions. The comments also indicate some errors in the VOC emission estimates in this draft and, as a result, some disagreement with suggested methods of VOC emission reduction or the amount of reduction achievable.

A summary of recommendations, based on those of the consultant, and those of the working group members, is being prepared.

The following possible government actions to facilitate product substitution, process changes or add-on controls for VOC emission management, were suggested by the consultant to the Miscellaneous VOC Sources Sub-Group.

"A. Target Areas and Priorities

The preliminary estimates of emissions of VOCs from consumer products Sub-Group 4 presented in Chapter III of Sub-Group report (9.4) suggests product areas that could potentially yield the largest reductions in VOC emission through product substitution, process changes, add-on controls and other control strategies. Paints and allied products, of the products considered in this study, offer the greatest potential VOC reduction. Substantial reductions are possible as well for automotive, household and personal use products.

The priority areas for consumer product VOC reductions need to be established before proceeding too far with programs to reduce VOC emission from consumer products. Additional work should be done to develop more accurate estimates of emission from some products, and to develop initial estimates in others. Priority should be given to developing VOC emission inventories for:

- pesticides;
- general solvent use.

Improved inventories of VOC emissions are needed for all other categories. This would include the extent of add-on control usage and product substitution practices.

B. Government Actions to Facilitate Reductions

1. Public Awareness

Through activities with manufacturing associations and public interest groups, actions could be taken to increase the awareness of the pollution which arises from use of consumer products and of the alternate choices that can be made to minimize VOC emissions. Such a program could include labelling of products to indicate VOC emission levels.

Increased awareness and product labelling could be the first level of a program to reduce emission on a voluntary basis. Labelling could logically be limited to high-emission products, such as solvents/thinners, oil-base paints, hair spray, deodorants, etc.

As part of this program, improved reporting of the solvent contents and quantities of products marketed would be needed to monitor progress and improve the confidence in estimates of VOC emissions.

2. Setting of VOC Emission Objectives

   The Government or an appropriate standards setting organization could develop standards for measurement of VOC emission levels of selected products, such as paints.

   More direct action could also be taken by Environment Canada to set VOC emission objectives for target products, much in the same way as is now done for point sources.

3. Regulation

   Regulations could be used to reduce VOC emissions from all consumer products by forcing reformulation of some products or removal from the market place of other products where reformulation is not possible or cost effective for manufacturers. Example regulatory approaches are:

   - banning of reactive VOCs used as propellants;
   - regulations limiting VOC emission characteristics of products such as paints, pesticides, selective household products etc.;
   - regulations requiring the labelling of emission levels of products and the solvents present.

4. Incentives

   Price dis-incentives could be used to encourage the user to select products emitting lower levels of VOCs. Consumers could be influenced in this manner to select lower emitting household, automotive, personal use, point and general purpose solvent products from the range of products now available. Emission charges could be placed on those products having higher VOC emission levels in cooperation with manufacturers. In other jurisdictions, the use of emission charges is being considered, with the monies collected being used to fund research and development of improved products.

   Research and development incentives could be offered to industry on a voluntary basis for work on development of products emitting less VOCs. Developers may have to be given exclusive rights to any new products created under such incentive programs to encourage continued development work and the participation of developers. Cost shared funding would possibly be appropriate.

5. Research and Development

Funding of scientific and engineering research on new materials and solvents in the product areas for concern would probably assist in development of products emitting less VOCs. This research would be of a more fundamental nature than specific product development work that might be done by manufacturers on their own or with incentives from government.

Technology transfer documents for industrial and commercial users of VOC emitting products that would assist them in improving operational and housekeeping practices, would be useful. Studies of interest include:

- best available technology for the application of coatings;
- VOC control systems - cost, performance, applications, etc;
- dispensers for consumer products and their transfer efficiency, cost, product uses, etc.;
- new more efficient means of application of pesticides."

Note: These suggestions by the consultant are to considered by the Miscellaneous VOC Sub-Group.

4.5 General common conclusions and recommendations which appeared to reflect consensus from the various Work Sub-Groups, were not developed in detail.

Obviously the quantity and quality of information available varies for the different NO_X and VOC emisison sources, and further studies and consultations could expand and refine the available information.

However, the CCME Technical Annex II and III (July 1989) and this report both provide overviews and perspectives on the various, NO_X and VOC emission sources and the associated standards and control options. This information will be useful in developing the NO_X/VOC Management Plan for Canada.

ANNEX 1.1

Members - Work Sub-Group 6.1

Mobile Sources - NO_X and VOC

Name	Organization	Comment
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Rick Godding	Canadian Automobile Association (CAA)	
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John Jeffries	Environment Ontario	
Glen Keller	Engine Manufacturer's Assoc.	
Yves Lemieux	Communauté Urbaine de Montreal (CUM)	
Karen Low	General Motors (GM)	
Brian McDonald	General Motors (GM)	
Morris Mennel	Greater Vancouver Regional District (GVRD)	
Mark Nantais	Motor Vehicle Manufacturers Assoc. (MVMA)	
Ted Orr	Assoc. of Can. Railways	
Bob Parker	John Deere	
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Ian Scott	Can. Petroleum Assoc. (CPA)	
Laura Tupper	Environment Canada	
Bruce Walker	STOP	
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Corresponding Members 6.1		
Philip Blagden	Newfoundland Environment	
Raynald Brulôtte	Environment Quebec	
Janine Ferretti	Pollution Probe	
Jim Knight	New Brunswick Environment	

NOTE: Addresses, phones and FAX numbers of participants are in Work Sub-Group reports, or are available from Sub-Group chairs or the NO_X/VOC Consultations Office.

ANNEX 1.2

Members - Work Sub-Group 6.2

Major Stationary Sources - NO_X

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Rod Platt	Can. Petroleum Assoc. (AMOCO)	
Farhad Seeif	Petroleum Assoc. for Conservation (PACE) (Petro Canada)	
Jochen Schmitz	Can. Gas Assoc./Can Petr. Assoc. (TransCanada Pipelines)	
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ANNEX 1.3

Members - Work Sub-Group 6.3

Major Stationary Sources - VOC

Name	Organization	Comment
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Fred Edgecombe	Environment and Plastics Institute of Canada	
Don Murray	Turbo Resources Inc.	
Don Skinner	Energy Mines & Resources Canada	
Bruce Walker	STOP	
Corresponding Members 6.3		
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M.S. Frost	Canadian Pulp & Paper Assoc.	
Jerry Lack	Alberta Environment	
Win Lee	Energy, Mines & Resources	
Luc Lefebvre	Communaute Urbaine de Montreal	
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Ken Smith	Environment Ontario	
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ANNEX 1.4

Members - Work Sub-Group 6.4

Miscellaneous Stationary Sources - VOC

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Tony Kosteltz	Environment Canada	
Malcolm MacGregor	Brown's Cleaners	
Peter Miasek	Esso Chemicals	
Dick Murry	Can. Paint and Coatings Assoc.	
Laurel Spielberg	City of Toronto	
Alan Wright	Maclean - Hunter Printing	

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1. Canadian Council of Ministers of the Environment (CCME), Federal/Provincial Long Range Transport of Air Pollutants Steering Committee (LRTAP), "Development of a National Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOC) Management Plan for Canada," Summary Report, April 1989, Updated, July 1989.

2. CCME, LRTAP, "Development of a NOx/VOC Management Plan, Technical Annex on 1. State of the Environment, II. The State of Atmospheric Chemistry and Implications for Control, III. Transboundary Flows" Spring 1989.

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9. Public Consultation Multistakeholder Work Groups for Development of NOx/VOC Management Plan, Control Technologies Work Sub-Group Reports:

   9.1 Work Sub-Group 6.1 "Mobile Sources - NOx and VOC," by F. Lavallée et al, Draft Dec. 1989, Final Jan. 1990.

   9.2 Work Sub-Group 6.2 "Stationary Sources - NOx," by P. Pinault et al, Jan. 1990.

   9.3 Work Sub-Group 6.3 "Large Stationary Sources - VOC," by B. Made et al, Draft Dec. 1989, Final Jan. 1990.

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CCME NO_x/VOC Consultation Plan

Report to the Federal-Provincial LRTAP Steering Committee

on

Status of National Inventory of NO_x/VOCs

December 1989
Revised: February 2, 1990

Inventory Management Division
Regulatory Affairs and Program
Integration
Ottawa, Ontario
K1A 0H3

February 5, 1990

Distribution:

Re: **Revised Report - Status of National Inventory of NO_x/VOCs**

Based on comments received, enclosed is the revised referenced report. Please note that provincial tables of the emissions of NO_x/VOCs, reflecting the changes made to the inventory, have now been included. The report as it stands will be used as input to the draft management plan for stakeholder consultation in March and April of this year.

Thanking you for your cooperation,

Yours sincerely,

Frank Vena
Chief

encl.

c.c.: R.M. Solman, NO_x/VOC Public Consultations Office

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APPENDIX:

. Submission from the Railway Association of Canada

. Personal communication, Dr. F. Edgecombe, Environment and Plastics Institute of Canada

. Personal communication, Harold Quinn, Contractor for the Canadian Chemical Producers Association

. Personal communication, Mark Nantais, Motor Vehicles Manufacturers' Association

. Levelton B.H. Reduction of VOC Emissions from Solvent Use by Product Substitution, Process Changes or Add-on Controls. Executive Summary. Report prepared for Environment Canada, December 1989

. Ortech. Preparation of a Canadian Inventory of Biogenic Organic Carbon Emissions from Vegetation. Report prepared for Environment Canada, December 1989

SUMMARY

Although a formal working group was not established following the September workshop, the participants in the inventory discussions felt that, for several sectors, the emissions and forecasts presented in the Federal/Provincial report: Development of a National Nitrogen Oxides (NO_x) and Volatile organic Compounds (VOCs) Management Plan for Canada, July 1989, needed further study.

It was agreed that the best way to update the 1985 baseline inventory and forecasts for those sectors of concern was to identify industry contacts that could speak on behalf of their industrial associations. Environment Canada also undertook to contact those stokehoders that were not present at the workshop but whose sector of activity was a potentially significant contributor to the emissions of NO_x/and or VOCs.

The sectors that have been revised as a result of new information are:

- railroads
- light-duty and heavy-duty vehicles
- solvent use in a variety of applications such as, dry cleaning, application of surface coatings, printing, household uses ...
- processing of resin into plastics

An estimate was also made of the natural emissions of VOC's from vegetation.

The impact of these modifications on the national inventory is summarized in tables 1 and 2.

TABLE 1 **National Emissions of NOx (kt)**

	1985	1990	1995	2000	2005
Light Duty Vehicles					
Automobiles	352 (391)	251 (332)	169 (262)	145 (246)	150 (262)
Gasoline Trucks	95 (123)	86 (138)	78 (140)	75 (128)	78 (120)
Diesel Trucks	6 (4)	7 (4)	7 (5)	8 (6)	11 (8)
Heavy-Duty Vehicles					
Gasoline Trucks	21 (25)	14 (29)	8 (34)	6 (39)	7 (44)
Diesel Trucks	264 (261)	322 (266)	241 (281)	231 (333)	254 (413)
Motorcycles	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Railroads	132 (140)	113 (144)	114 (155)	113 (164)	113 (176)
TOTAL: Revised Sectors	871 (945)	794 (914)	618 (883)	579 (917)	614 (1024)
TOTAL: Other Sectors	1014	1084	1178	1262	1290
NATIONAL TOTAL	1885(1959)	1878(1998)	1796(2054)	1841(2179)	1904(2314)
PERCENT CHANGE	-3.8	-6.0	-12.6	-15.5	-17.7

() Ref.: CCME, July 1989.

TABLE 2 **National Emissions of VOCs (kt)**

SECTOR	YEAR				
	1985	1990	1995	2000	2005
Light Duty Vehicles					
Automobiles	412 (471)	334 (388)	256 (297)	230 (263)	237 (264)
Gasoline Trucks	143 (192)	128 (182)	114 (149)	105 (131)	108 (123)
Diesel Trucks	1 (1)	2 (1)	2 (2)	3 (2)	4 (3)
Heavy-Duty Vehicles					
Gasoline Trucks	25 (29)	10 (25)	6 (21)	5 (21)	5 (23)
Diesel Trucks	29 (35)	30 (37)	33 (40)	38 (47)	44 (58)
Motorcycles	3 (4)	3 (5)	3 (5)	3 (5)	4 (6)
Railroads	7 (10)	5 (11)	5 (11)	5 (12)	6 (13)
Plastics Processing	14 (48)	16 (52)	21 (59)	22 (68)	28 (80)
Solvent Use	502 (290)	536 (317)	563 (333)	585(347)	603(359)
TOTAL: Revised Sectors	1136(1080)	1064(1076)	1003(917)	996(896)	1039(929)
TOTAL: Other Sectors	718	687	818	909	1008
NATIONAL TOTAL	1854(1798)	1751(1763)	1821(1735)	1905(1805)	2047(1937)
PERCENT CHANGE	+3.1	-0.7	+5.0	+5.5	+5.7

() Ref.: CCME, July 1989.

VOC Emissions from vegetation: 11.1 million tonnes

Those sectors for which work is on-going and for which revised emission estimates and forecasts should be available during the preparation of the management plan are:

- petrochemical plants
- petroleum refineries
- petroleum production
- natural gas production

1. SECTOR REVIEWS

1.1 Light and Heavy-duty Vehicles

The sectors of the national inventory comprising on-road motor vehicles include:

Light-duty Vehicles:
- automobiles
- light-duty gasoline trucks
- light-duty diesel trucks

Heavy-duty Vehicles:
- Heavy-duty gasoline trucks
- Heavy-duty diesel trucks

Motorcycles

Emission inventories for on-road motor vehicles are derived by multiplying the number of vehicles by the average miles travelled per year and by an emission factor in grams per mile for each pollutant and each class of vehicle. This emission factor is calculated using a computer modeling program. For the 1985 base year inventory, these emission factors were calculated using MOBILE3C while the inventory in this report was calculated using MOBILE4C. These are "Canadianized" versions of emission factor programs developed by the U.S. Environmental Protection Agency (EPA, 1989). Hence the use of grams per mile emissions rates used in the U.S. The following section will describe in general how emission factors are derived, the differences between MOBILE3 and MOBILE4, the changes made to MOBILE4 in order to better reflect calculation methodology used to develop the inventory.

The data used to develop emission factor programs comes from thousands of tests done over the years. Most of this testing was done by the EPA, but data from all sources was used including test data from Environment Canada.

MOBILE4 can calculate an average emission factor for each type of vehicle for each calendar year from 1960 to 2020 for VOCs, NO_x (and carbon monoxide). The average for each type of vehicle and pollutant is calculated by adding the contribution of each of the 20 previous model years. The emission rate from each model year is calculated by multiplying a deterioration rate in grams per 10,000 miles by the average mileage of the cars of that particular model year and adding the product to a constant called the base emission rate for that model year. Besides this basic calculation MOBILE4 incorporates subroutines to calculate the effect of temperature, speed, tampering and many other factors.

A great deal of new information on vehicle emissions has become available since the introduction of MOBILE3 and for this reason, the EPA has

developed MOBILE4. While many of the changes have a relatively minor effect on the emission factors generated, there are two large changes between MOBILE3 and MOBILE4. These are the introduction of subroutines to calculate running losses and to calculate the effect of fuel volatility and ambient temperature on emissions. Running losses have only recently been discovered. The are evaporative emissions which occur while the vehicle is being driven. Running losses are not measured during the certification test procedure and it was wrongly assumed that theses losses were low in vehicles in-use. Evaporative VOC emissions can be as high or higher than tailpipe VOC emissions during very "hot" summer days. MOBILE3 had a fixed evaporative emission factor that did not take into account running losses.

MOBILE4 was changed to better reflect the Canadian fleet emissions only where there were significant differences between the U.S. and Canadian vehicles and where sufficient information was available to justify the numbers used. Three major changes were done to MOBILE4. The base emission rate and deterioration rate, the fleet technology penetration (used to calculate tampering effects) and evaporative emission rates for light-duty vehicles were changed for the 1980 to 1987 model years. The changed program is referred to as MOBILE4C.

In order to better model the Canadian fleet it was decided to develop emission factors for each province (Table 3). MOBILE4C uses a maximum and minimum temperature to calculate emission factors. The year was divided into 4 periods that correspond to the periods used to limit gasoline RVP in the Canadian General Standards Board (CGSB) specification or in provincial regulations. The average maximum and minimum temperature for each period was calculated for the largest city in each province using monthly average maximum and minimum temperatures. This average is based on twenty years of data from 1951 to 1980 (Environment Canada, 1982). Provincial registration information was used to develop a unique light-duty vehicle age profile for each province (Desrosiers, 1988; Statistics Canada, 1986a). A city and highway emission factor was calculated for each of these periods and combined (55% urban/45% highway) to calculate a composite fleet average emission factor.

Changes between MOBILE3C and MOBILE4C Emission Factors (Lavallée, 1989).

Volatile Organic Compounds

There are large changes in certain emission factors between those calculated using MOBILE3C and those using MOBILE4C. Although it was expected that the introduction of running losses in MOBILE4 would result in higher emission factors for VOCs from gasoline powered vehicles than was the case with MOBILE3, this has not happened. The reasons for this are many and complicated, but part of this result can be explained by the methodology used to model Canadian emissions with MOBILE3C.

When MOBILE3C was first used, there was essentially no information readily available on the emissions of Canadian motor vehicles in the 1980 to 1987 model year. It was decided to simply offset the MOBILE3 model years.

This meant that the emission factors generated up to 1980 were the same for both programs, but the emissions factors for 1981 U.S. fleet corresponded to the 1984 Canadian fleet and the emission factors for the 1982 U.S. fleet corresponded to the 1988 Canadian fleet. Emission factors for the intervening years were interpolated between these points. This shift gave approximately the right mix of three way catalysts, oxidation catalysts and non catalyst cars. However, while the technology mix was right, emissions from the Canadian fleet in the 1981 to 1988 period were lower than the MOBILE3C forecast by offsetting the emission factors. This occurred because the 1981 U.S. fleet still contained many vehicles of pre-1975 vintage. However, in the actual Canadian fleet, the new vehicles sold from 1981 to 1987 vehicles had much lower tailpipe VOC and evaporative emissions than the older pre-1975 vehicles they replaced. Therefore, the shift resulted in our overstating Canadian fleet emissions.

In general, the areas in Canada with large vehicle populations are much colder than similar areas in the U.S. and this has reduced the effect of the addition of running losses. MOBILE4 and MOBILE4C assume that running losses stop below 40 degrees Fahrenheit. The average temperature for 5 months of the year is below this temperature in most of Canada. This has reduced the impact of adding running losses on overall VOC emissions.

While the changes in emission factors account for most of the change in VOC emissions, some of the changes are due to different fleet growth projections. This is particularly true for heavy duty gasoline trucks. While they are a relatively small source, the large drop in projected population has reduced overall VOC emissions. The gasoline trucks which are high VOC emitters are being replaced by diesel trucks that have much lower VOC emissions.

Nitrogen Oxides (NO_x)

It was anticipated that NO_x emissions would be lower with MOBILE4 than with MOBILE3. MOBILE4 tailpipe emissions projections are generally lower for all vehicles and all pollutants. This is because of lower tampering rates and better performance (lower deterioration rates for untampered vehicles in-use) than originally expected from the emissions control systems.

Large trucks have the largest projected decrease over the previous projections. MOBILE3 assumed that the heavy duty vehicles would have a 6.0 gram per brake-horsepower-hour standard, but in fact the U.S. will have a 5.0 gram standard beginning in 1991. The factor used to convert grams per brake horse-power-hour to grams per mile was also changed. Trucks are more energy efficient than forecast and this gives a lower conversion factor. The third major reason for a lower NO_x emission factor is that MOBILE4 has a zero deterioration factor for NO_x. Data from tests of in-use trucks show that NO_x emissions from heavy-duty diesel engines does not increase with mileage. There are no changes in the emission factor calculations for heavy duty vehicles between MOBILE4 and MOBILE4C.

TABLE 3 WEIGHTED AVERAGE NOX/VOC EMISSION FACTORS FROM ON-ROAD MOTOR VEHICLES - 1985 -

VOC Emission Factors (g/mile)

Province	AUTOS	LDGT	LDDV	HDGT	HDDV	MOTORCYCLES
Newfoundland	3.165	4.877	0.544	7.773	2.629	4.029
Prince Edward Island	3.239	4.829	0.544	8.066	2.629	4.066
Nova Scotia	3.239	4.829	0.544	8.066	2.629	4.066
New Brunswick	3.364	4.942	0.544	8.003	2.629	4.018
Quebec	3.472	5.083	0.544	8.601	2.629	4.483
Ontario	3.700	5.101	0.544	8.746	2.629	4.684
Manitoba	4.549	5.576	0.544	8.708	2.629	4.455
Saskatchewan	4.701	5.659	0.544	8.752	2.629	4.532
Alberta	4.113	5.224	0.544	8.431	2.629	4.185
British Columbia/ Yukon/North West Territories	4.176	5.260	0.544	10.540	2.629	4.067

NO_x Emission Factors (g/mile)

Province	AUTOS	LDGT	LDDV	HDGT	HDDV	MOTORCYCLES
Newfoundland	3.081	3.591	2.080	7.454	24.320	1.009
Prince Edward Island	3.057	3.521	2.080	7.371	24.320	0.984
Nova Scotia	3.057	3.521	2.080	7.371	24.320	0.984
New Brunswick	3.134	3.571	2.080	7.437	24.320	0.999
Quebec	3.075	3.539	2.080	7.388	24.320	0.964
Ontario	3.179	3.530	2.080	7.373	24.320	0.964
Manitoba	3.508	3.662	2.080	7.545	24.320	0.974
Saskatchewan	3.568	3.682	2.080	7.571	24.320	0.984
Alberta	3.450	3.627	2.080	7.493	24.320	1.009
British Columbia/ Yukon/North West Territories	3.343	3.460	2.080	7.275	24.320	0.989

The emissions of NO_x and VOCs for the base year 1985 calculated using MOBILE4C are presented in Tables 4 and 5. The emission estimates derived from MOBILE3C and used in the CCME report are shown for ease of comparison.

Projections

In addition to the emission factors generated by MOBILE4C for the years 1986-2005 for the two pollutants by vehicle type and by province, the Motor Vehicle Manufacturers' Association (MVMA) provided revised estimates of new vehicle sales projections (Nantais, 1989). These sales forecasts were introduced into the National Energy Board (NEB) model on transportation systems, resulting in output of growth in the stock of the various vehicle types. The NEB data had been used in the previous estimates of the CCME report, and these changes are a reflection of the revised MVMA submission. For light-duty diesel trucks, however, due to a lack of new data, the previous growth estimates have been used.

A comparison of the new MVMA sales data, when converted to growth in vehicle fleet, with the data used to develop projections for the CCME report, show small differences for all vehicle types excepts for heavy-duty gasoline trucks. For these vehicles, the NEB model shows a decrease in the fleet size over the time period of interest. A summary of the growth rates is shown in table 6.

TABLE 6

GROWTH IN VEHICLE STOCK*
1985 - 2005

Vehicle Type	New data	CCME report
Automobiles	1.41	1.47
Light-duty gasoline Trucks	2.08	1.83
Heavy-duty gasoline Trucks	0.45	1.83
Light-duty Diesel Trucks	2.83	2.83
Heavy-duty Diesel Trucks	2.75	2.83

* Data have been calculated by province. These figures have been weighted according to provincial fleet projections.

National emission projections of NO_x and VOCs using MOBILE4C are presented in tables 4 and 5, respectively.

TABLE 4

NATIONAL EMISSION PROJECTIONS OF VOCs (kt)
ON-ROAD MOTOR VEHICLES

SECTOR	YEAR				
	1985	1990	1995	2000	2005
Light Duty Vehicles					
Automobiles	412 (471)	334 (388)	256 (297)	230 (263)	237 (264)
Gasoline Trucks	143 (192)	128 (182)	114 (149)	105 (131)	108 (123)
Diesel Trucks	1 (1)	2 (1)	2 (2)	3 (2)	4 (3)
Heavy-Duty Vehicles					
Gasoline Trucks	25 (29)	10 (25)	6 (21)	5 (21)	5 (23)
Diesel Trucks	29 (35)	30 (37)	33 (40)	38 (47)	44 (58)
Motorcycles	3 (4)	3 (5)	3 (5)	3 (5)	4 (6)
TOTAL	**613 (732)**	**507 (638)**	**414 (514)**	**384 (469)**	**402 (477)**
% Change	-16	-21	-20	-18	-16

() Ref.: CCME, July 1989

TABLE 5

NATIONAL EMISSION PROJECTIONS OF NO_x (kt)
ON-ROAD MOTOR VEHICLES

SECTOR	YEAR				
	1985	1990	1995	2000	2005
Light Duty Vehicles					
Automobiles	352 (391)	251 (332)	169 (262)	145 (246)	150 (262)
Gasoline Trucks	95 (123)	86 (138)	78 (140)	75 (128)	78 (120)
Diesel Trucks	6 (4)	7 (4)	7 (5)	8 (6)	11 (8)
Heavy-Duty Vehicles					
Gasoline Trucks	21 (25)	14 (29)	8 (34)	6 (39)	7 (44)
Diesel Trucks	264 (261)	322 (266)	241 (281)	231 (333)	254 (413)
Motorcycles	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
TOTAL	**739 (805)**	**681 (770)**	**504 (723)**	**466 (753)**	**501 (848)**
% Change	-8	-12	-30	-38	-41

() Ref.: CCME, July 1989

1.2 Railroads

The Railway Association of Canada (RAC) provided historical data and calculated projections of railway traffic, fuel and locomotive emissions for the period 1975 to 2005 (Ballantyne, 1989). For the period of interest to the CCME NO_x/VOC Consultation Plan, the emission data provided are summarized in Table 7.

TABLE 7 **National Emissions from Rail Transport (kt)**

	1985		1990		1995		2000		2005	
Sector	**NOx**	**VOCs**	**NOx**	**VOCs**	**NOx**	**VOCs**	**NOx**	**VOCs**	**NOx**	**VOCs**
Rail Transport										
.Freight	116	6	108	5	109	5	108	5	108	5
.Passenger	16	1	5	<1	5	<1	5	<1	5	<1
TOTAL	132	7	113	5	114	5	113	5	113	6
TOTAL (CCME, July 1989)	140	10	144	11	155	11	164	12	176	13

The differences between the emission estimates in the CCME report and those by RAC for the base year inventory lie with the emission factors. The American Association of Railroads report used by RAC to develop emission factors for Canadian locomotives has only recently been published and was not available at the time the CCME estimates were being compiled. The data represents testing of 57 locomotives between 1981-1983 and are the most current and complete.

TABLE 8 **Rail Locomotive Emission Factors (kg/10^3 litres)**

	NO_x	**VOCs**
RAC (AAR, 1989)	55.6	2.7
CCME (EPA, 1986)	63.4	4.9

Although both estimates (RAC and CCME) relied on Statistics Canada for fuel consumption figures for the base year 1985, there is an apparent discrepancy in the data reported. The figures reported in catalogue 57-003, Quarterly Report on Energy Supply-Demand in Canada, (1985) are lower by about 7% from those in catalogue 52-215, Railway Transport in Canada, General Statistics, (1985). The figures in the latter report appear to be suspect. This inconsistency cannot be resolved at this time but the impact on base year emissions is minimal.

Projections

The RAC also provided projections of NO_x and VOC emissions for both freight and passenger trains. In Table 7 emissions are shown to decrease between 1985 and 1990 and then remain relatively constant throughout the forecast period. The RAC, in providing its forecasts, makes several assumptions:

- locomotives will begin to be replaced starting in 1995 at the rate of 40 per year. These new engines will be more fuel efficient and result in NO_x emissions per unit 10% lower than existing engines
- projected traffic volume increases and reduced fuel consumption per ton-mile (as a result of engine modification and operational improvement) will result in future fuel consumption remaining relatively stable
- reduced passenger service starting in 1990 will result in reduced fuel consumption
- consumption will remain constant after this time

If these assumptions hold true, the emissions as shown in Table 7 appear reasonable.

1.3 Plastics

The methodology used to derive the emission estimates in the CCME, report relied on emission factors available from the U.S. literature (Hughes et al, 1978) and total resin consumption in dollar value reported by Statistics Canada (Statistics Canada, 1986b). Resin consumption data by process were not available and consequently an aggregate process emission factor based on the Hughes report was developed.

In an effort to better reflect Canadian processes and emission factors, the Environment and Plastics Institute of Canada (EPIC) provided resin consumption estimates by process and emission factors for a large number of these processes (Edgecombe, 1989). Some of these factors were based on test data, while the majority were based on industry knowledge of the processes; where information was not available, the factors reported by Hughes were used.

This new information and the resulting emissions are summarized in Table 9. It should be noted that emissions form polystyrene foam, where the blowing agents used are chlorofluorcarbons (CFCs), and from phenol formaldehyde foams, where the blowing agents are CFCs and methylene chloride, have been set to zero. These compounds are the principal organic compounds

TABLE 9 EMISSIONS OF VOCs FROM PLASTICS PRODUCTION - 1985.

RESIN	PROCESS	RESIN PROCESSED (kt)	E.F.* (g/kg resin)	EMISSIONS (tonnes)
Polystyrene	Foam HCs	27.0	50.0	1350
	Foam CFCs	28.0	0.0	0
	Injection mould	135.0	1.0	135
Polyester	Lamination/therm	12.2	82.0	1000
	Lamination/bats	39.0	40.5[1]	1580
Polyethylene	Film Extrusion	185.0	1.5	278
	Moulding	503.0	1.0	503
PVC	Extrusion/ injectn moulding	327.0	5.0	1635
Polypropylene	Film Extrusion	74.5	1.5	112
	Injection mould	74.5	1.0	75
ABS	Extrusion/mould	52.0	1.0	52
Acetal	Moulding	2.0	1.0	2
Acrylic	Coatings	26.0	20.0[1]	520
Epoxy	Coatings	12.0	25.0[1]	300
	laminates	3.0	25.0[1]	75
Phenol form-aldehyde	Adhesives	28.0	25.0[1]	700
	Moulding	17.0	33.5[1]	570
	Foams	11.0	0.0	0
Polyamide	Moulded	15.0	20.0[1]	300
	Extruded	74.0	5.0	370
Polycarbonate	Moulded	9.0	32.0[1]	288
Polyesters (Thermoplastic)		70.0	1.0	70
Polyphenylene	Injectn mould	3.0	20.0[1]	60
Polyurethane	Flex. foam	33.6	0.0	0
	Rigid foam	76.0	1.0	76
	Thermoplastic	2.4	46.0[1]	110
Urea form-aldehyde	Adhesives	98.0	25.0[1]	2450
	Moulding	33.0	20.0[1]	660
Other	Moulding	21.0	20.0[1]	420
Totals		1991.2		13,691 (48,619)

* Emission Factors provided by EPIC, unless otherwise indicated.
[1] Hughes et al, 1978
() CCME, July 1989

released during these processes but are excluded from the definition of VOCs since they are not reactive and do not take part in ozone formation.

Although the emission factors provided by EPIC are more current and more representative of Canadian processes and practices than those reported by Hughes et al, additional work is required to adequately characterize the emissions of VOCs from the plastics processing sector. In the interim, the estimates presented in Table 9 will supercede those presented in the CCME report.

Projections

Data provided by EPIC indicate that for the period 1982-89, growth in the plastics industry averaged 5.3% per year, whereas the Canadian economy grew at a rate of 3.3% per year. Large fluctuations occurred in growth on a year-to-year basis as shown by the following:

1986 - 1%
1987 - 6%
1988 - 3%
1989 - 0%

These data are considered more representative and are used in generating the forecasts. For the period 1990-1996, a growth rate of 5.6% per year has been estimated by EPIC. Since EPIC does not provide any estimates for the years after 1996, the Informetrica (Informetrica, 1989) estimate for growth of 2.9% per year has been used to the year 2005. The emissions have been calculated using an industry aggregated emission rate that is assumed to be constant throughout the forecast period and are as follows:

TABLE 10 NATIONAL EMISSION PROJECTIONS OF VOCs - Plastics Production (kt)

1985	1990	1995	2000	2005
14 (48)	16.0 (52)	21 (59)	22 (68)	28 (80)

() Ref.: CCME, July 1989.

1.4 **Solvent Use**

During this phase of the NO_x/VOC consultations, Environment Canada commissioned a report to assess the potential for emission reduction from the use of solvents (Levelton, December 1989). The report examined the existing VOC emission estimates from solvent use and modified these estimates where better data were found. In particular improved data on solvent usage were compiled using estimates developed from published industry statistics (Miasek, 1989). The revised emission estimates presented in this report are based primarily on these data.

The original methodology for estimating VOC emissions from the use of solvents was broken down into three sectors:
- dry cleaning
- application of surface coatings
- general solvent use.

TABLE 11 SOLVENT USAGE* AND EMISSIONS (kt)

SECTOR	HYDROCARBON	ALCOHOLS	KETONES	GLYCOL/ETHER	ESTERS	HALOGEN	N-BASED	TOTAL	VOC EMISSIONS**
PAINT/COATING APPLICATIONS	134	21	17	8	6	1.5	-	188	187.5
GLUES/ADHESIVES/SEALANTS	24	1.4	3	1	4	1.5	-	35	35.
PRINTING	25	6	-	1.5	6	-	-	38.5	20
INDUSTRIAL DEGREASING	11	1	-	1	-	21	-	34	17.5
DRY CLEANING	3	-	-	-	-	10.4	-	14	14
CONSUMER PRODUCTS:									
Auto care/maintenance	1	31	-	89	-	-	-	121	37
Household clean/polish	9	-	-	1	1	0.5	-	11.5	11.5
Personal care products	-	18	1	3	-	-	-	22	22
AEROSOL PROPELLANTS	11	-	-	-	-	3.8	-	15	11
PESTICIDES	11	-	-	-	-	-	-	11	11
OTHER:									
Pharmaceiclas & food processing	-	2.2	-	-	-	-	-	2	2
Natural oils extraction	10	-	-	-	-	-	-	10	10
Photocopy	1	-	-	-	-	-	-	1	1
Paint strippers	-	2	-	-	-	4	-	6	2
Wood preservation	2	-	-	-	-	-	-	2	2
Oilfield Chemicals	-	-	-	8	-	-	10	18	18
Rubber Products	4	-	0.5	-	-	-	-	4.5	4.5
Petroleum refining	-	-	1.5	-	-	-	-	1.5	1.5
Polyofefin manufacture	4.5	-	-	-	-	-	-	4.5	4.5
Blowing agents[1]	1.5	-	-	-	-	8.7	-	10.2	-
Mining	1	4	-	-	-	-	-	5	5
Calendaring	-	-	3	-	-	-	-	3	3
Electronics manufacture	-	-	-	-	-	1	-	1	-
Metal rolling	1	-	-	-	-	-	-	1	1
Refrigerant	-	-	-	-	-	8.5	-	8.5	-
Water treatment	1	-	-	-	-	-	0.5	1.5	1.5
MISCELLANEOUS	66	5.6	7	-	1	1.4	-	81	79.5
TOTALS	321	92.2	33	112.5	18	62.3	10.5	650.9	502 (290)

* - Summary of estimates developed by P.G. Miasek of ESSO Chemicals Canada, 1989, based on published information.

** - VOC emission estimates developed by Levelton & Associates, and Environment Canada. Non-reactive solvents are not included.
- Where emission reduction information is not yet available, it is assumed all reactive solvents used are eventually emitted.
- Quantities of solvents whose end uses are as fuel or venversion to another substance, are not included included in these totals.

[1] Emissions included under Section 1.3 Plastics

() CCME, July 1989.

The Levelton report also includes several categories of solvent use that were not included in the CCME inventory. They are: glues and adhesives, pesticides and miscellaneous industries (e.g.. rubber products, natural oil extraction, pharmaceutical and food processing...). It should be noted that some chlorinated solvents such as chlorofluorcarbons (CFCs), methylene chloride and 1,1,1, trichloroethane, are excluded from the definition of VOCs(see Section 1.3).

Table 11 shows the consumption patterns of solvents used in Canada, and summarizes the emissions of VOC's from the use of these solvents. The methodologies and information sources used to derive these estimates can be found in the Levelton report.

Projections

Emission forecasts from the use of solvents have been generated using the new base year estimates and the growth factors as applied in the CCME report. The growth in the number of households (Informetrica, 1985) and population figures from Statistics Canada (statistics Canada, 1985) were used to generate forecasts for surface coatings and dry cleaning and solvent use, respectively. The data can be summarized as follows:

TABLE 12

VOC EMISSION PROJECTIONS - NATIONAL (kt)
SOLVENT USE

	1985	1990	1995	2000	2005
Application of Surface coatings	187.5	207.8	223.9	238.7	253.6
Dry Cleaning	14.0	14.6	15.0	15.3	15.5
Other solvent use	300.5	314.0	323.8	330.5	334.0
TOTAL	502.0(290)	536.4(317)	562.7(333)	584.5(347)	603.1(359)

() Ref.: CCME, July 1989

1.5 Emissions of VOCs from Vegetation

In order to provide as complete a picture as possible of the emissions of VOCs, the contribution from natural sources was also examined. One of the most important sources is vegetation consequently, a Canadian inventory of biogenic emissions from canopy and non-canopy vegetation has been prepared (Ortech, December 1989). The methodology used and findings form part of the appendix to this report.

In summary canopy emissions were estimated using an eight-layered canopy model developed by B. Lamb at Washington State University, 1989.

Emission factors at a standard temperature of 30°C for isoprene, alpha-pinene, other mono-terpenes and other unknown hydrocarbons were corrected using hourly temperature, wind, humidity and cloud data for thirty-three climate zones. The hourly zonal factors were averaged to produce monthly averages. These monthly emission factors were applied to monthly biomass estimates on a 127 x 127 km grid to obtain Canadian and provincial annual and seasonal emissions for 1985. Total biogenic VOC emissions were 11.1 million tonnes . The summer season accounts for approximately 53 percent of the emissions. On an annual basis, isoprene accounts for 12 percent, alpha-pinene and other mono-terpenes each for 25 percent, with the balance of 38 percent made up of unknown hydrocarbons. Twenty five (25) percent of the emissions of the unknown hydrocarbons are considered to be reactive alkenes.

On the basis of this estimate, anthropogenic emissions would only constitute 14 percent of the total VOC in Canada. On a flux basis, however, in urban areas where most of the other chemical reactants are emitted, the emission flux of natural VOC would be very much smaller than from the anthropogenic sources. Some of the natural VOC would mix and react with anthropogenic emissions in urban plumes, while the major portion would only encounter urban emissions through much slower regional mixing.

Figure 3.1 to 3.3 provide national and provincial emissions of biogenic VOCs from vegetation.

1.6 Other Sectors

Other Sectors

Work is also being done to revise, where necessary, the emission estimates and forecasts from a number of other sectors. These are:
- petrochemical plants
- petroleum refineries
- petroleum production
- natural gas production

To date, some preliminary data are only available from the petrochemical sector.

As noted in the July CCME report, the emission estimates presented from the petrochemical sector did not take into account the control practices currently in place in the industry and hence, were more reflective of uncontrolled operations. A working group was established with the Canadian Chemical Producers Association (CCPA) to refine the estimates of the inventory through a questionnaire survey of the major chemical producers. Preliminary data received to date indicates that the largest VOC-containing sources are sent to a flare or furnace which destroys essentially all of the organic molecules. (Quinn, 1989). Flare efficiencies in the order of 98 to 99.5% efficiency have generally been assumed.

These data suggest that the emission estimates from process sources presented in the CCME report would be reduced substantially. Data on fugitive emissions, the other major source in petrochemical plants, are not yet available.

FIGURE 1

NATIONAL EMISSIONS OF VOCs FROM VEGETATION

SEASONAL BREAKDOWN (1985)

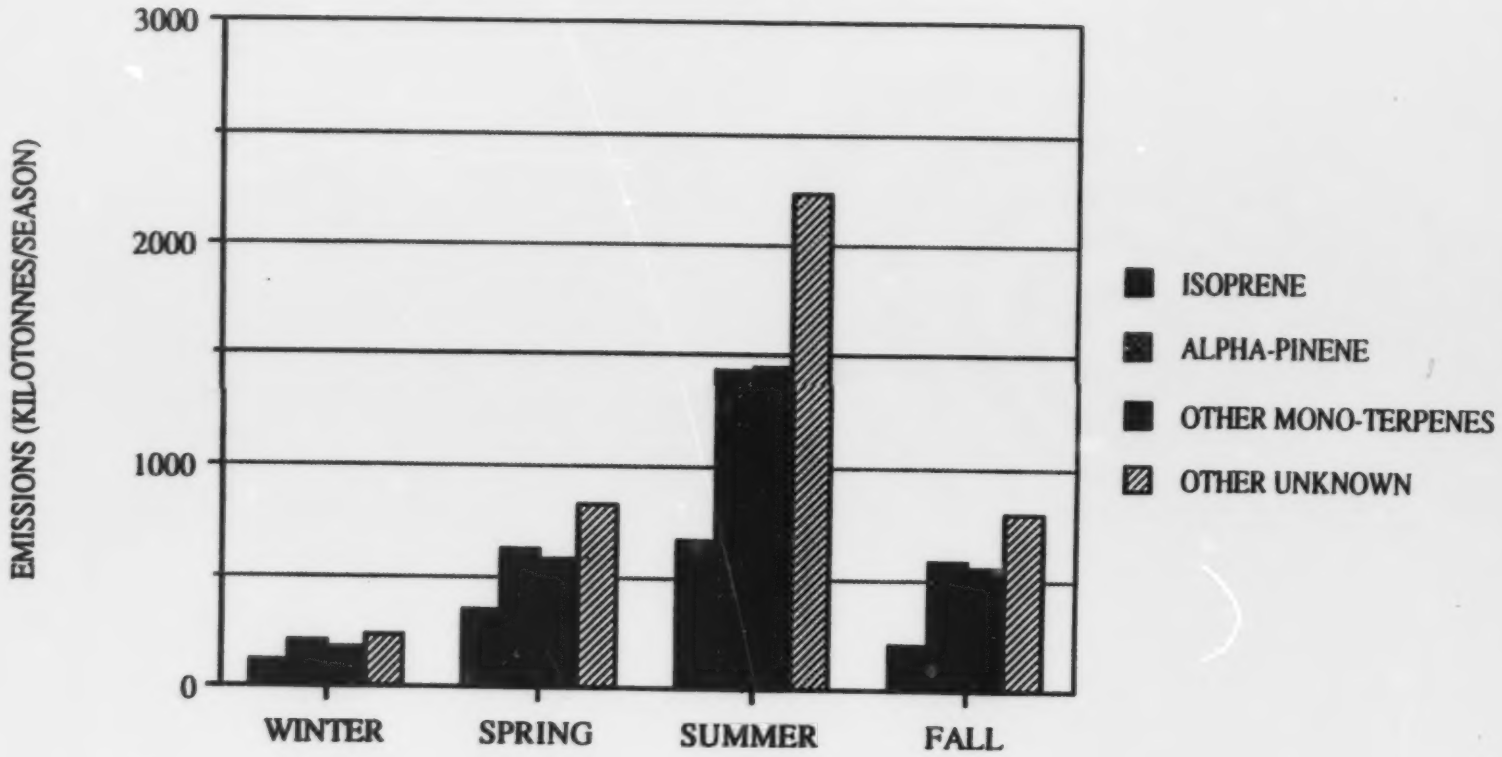


FIGURE 2

PROVINCIAL EMISSIONS OF VOCs FROM VEGETATION

SEASONAL BREAKDOWN (1985)

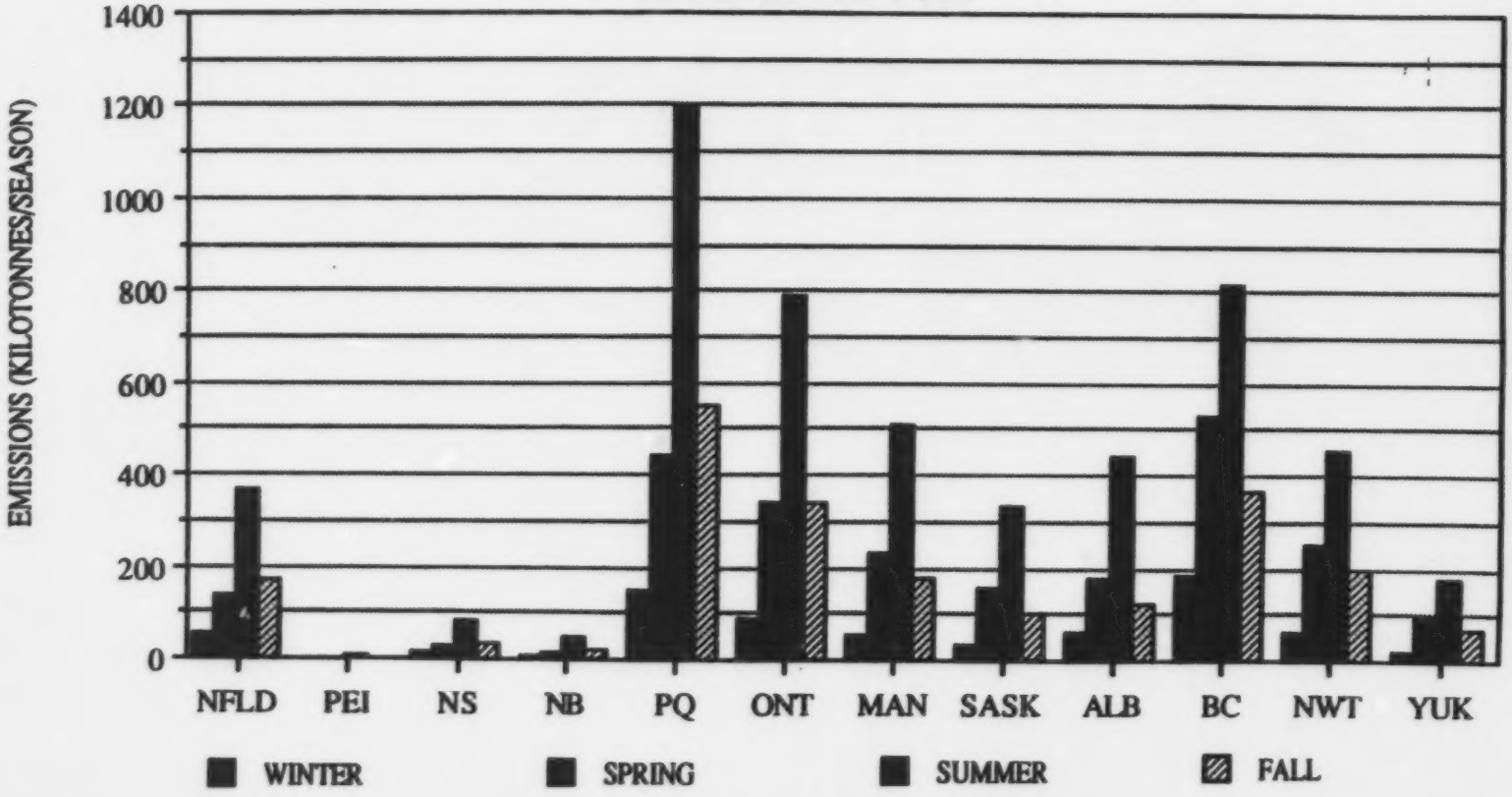
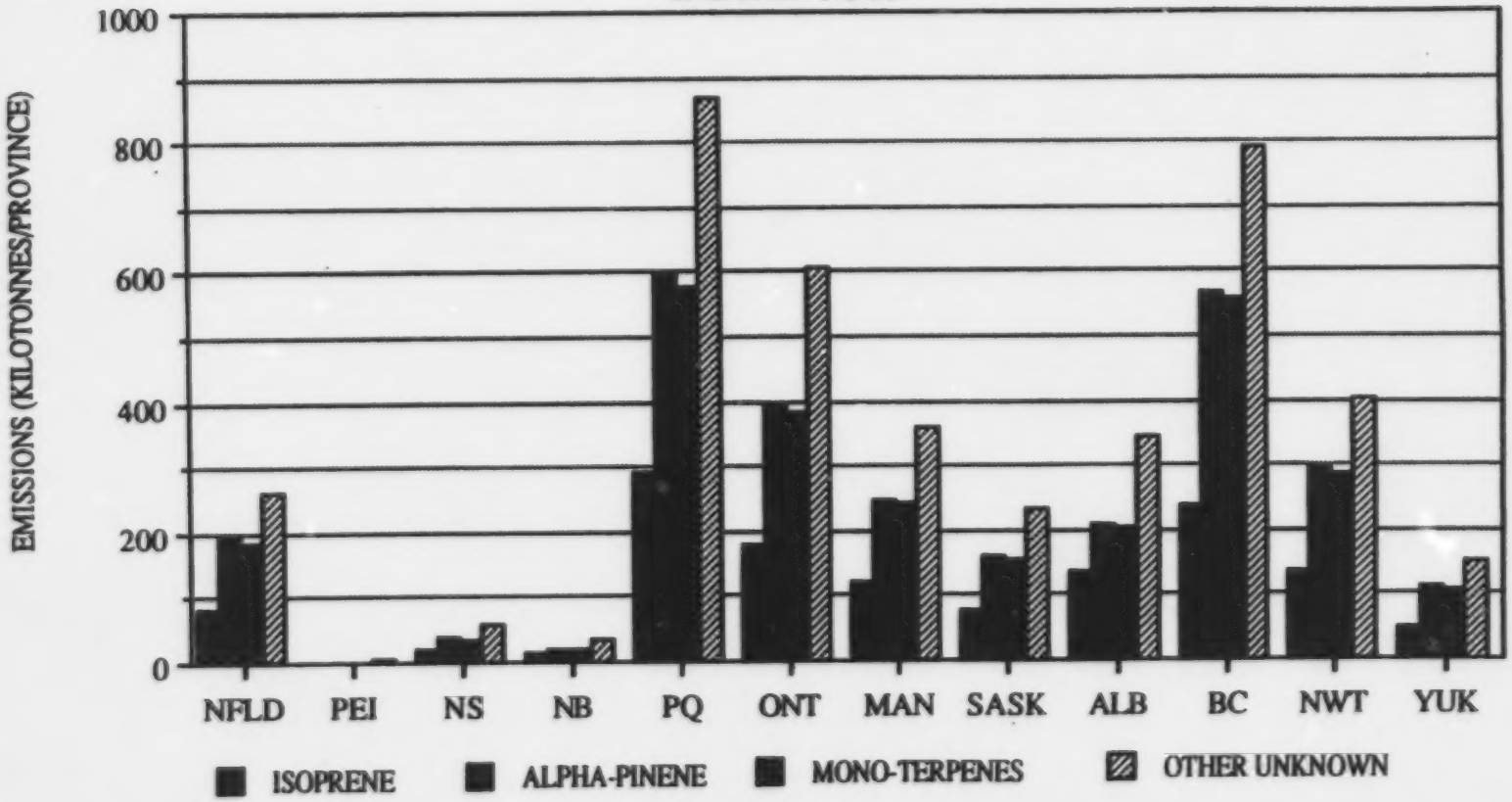


FIGURE 3

PROVINCIAL EMISSIONS OF VOCs FROM VEGETATION

BY SPECIES (1985)



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APPENDIX

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Canada

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	412.7	334.0	256.1	229.4	237.3
Light-Duty Trucks					
Gas	142.7	127.9	113.7	104.8	108.9
Diesel	1.4	2.1	2.1	2.9	3.7
Heavy-Duty Trucks					
Gas	25.1	9.9	5.5	4.2	4.3
Diesel	28.7	30.4	33.4	37.7	43.5
Off-Road Gasoline	66.1	64.8	66.5	70.3	74.3
Other	72.6	76.1	79.5	82.8	89.0
Fuel Combustion					
Fuelwood	107.7	111.8	119.3	128.5	132.7
Residential/Commercial	3.7	3.5	3.5	3.5	3.5
Industrial	49.5	46.0	52.1	57.3	63.9
Industrial Processes					
Petrochemicals	107.8	114.4	134.4	165.2	206.8
Petroleum Refining	40.3	42.7	44.4	46.5	49.3
Plastics	13.6	16.0	20.9	25.6	29.4
Crude Oil	15.0	14.9	18.2	26.2	28.3
Other	46.7	51.2	62.1	71.1	81.1
Incineration/Miscellaneous					
Surface Coatings	187.5	207.5	223.9	238.7	253.6
Fuel Marketing	109.0	109.0	113.7	119.1	124.4
Dry Cleaning	14.0	14.5	15.0	15.3	15.5
Solvent Use	300.5	314.0	323.6	329.9	333.8
Slash Burning	80.6	89.8	101.7	113.6	129.0
Other	25.6	25.7	28.0	29.7	32.4
Power Generation	2.7	2.7	2.7	2.7	2.7
T O T A L	1853.5	1808.9	1820.3	1905.0	2047.4

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Newfoundland

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	5.1	3.7	2.5	2.3	2.4
Light-Duty Trucks					
Gas	2.8	2.4	2.1	1.9	2.0
Diesel	< 0.1	< 0.1	< 0.1	0.1	0.1
Heavy-Duty Trucks					
Gas	0.7	0.2	0.1	0.1	0.1
Diesel	0.6	0.8	0.9	1.1	1.2
Off-Road Gasoline	2.7	2.9	3.1	3.5	3.8
Other	2.3	2.4	2.6	2.7	2.8
Fuel Combustion					
Fuelwood	8.7	8.7	9.1	9.4	9.8
Residential/Commercial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial	< 0.1	0.1	0.1	0.1	0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	-	-	-	-	-
Plastics	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Crude Oil	-	-	1.7	9.0	11.0
Other	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Incineration/Miscellaneous					
Surface Coatings	2.8	3.0	3.3	3.4	3.5
Fuel Marketing	1.9	1.9	2.0	2.0	2.1
Dry Cleaning	0.3	0.3	0.3	0.4	0.4
Solvent Use	6.0	6.4	6.7	7.0	7.2
Slash Burning	1.4	1.7	1.8	2.0	2.5
Other	0.1	0.1	0.1	0.1	0.1
Power Generation	0.2	0.2	0.2	0.2	0.2
T O T A L	35.6	34.7	36.5	45.2	49.3

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Prince Edward Island

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	1.7	1.3	0.9	0.8	0.9
Light-Duty Trucks					
Gas	0.7	0.6	0.6	0.5	0.5
Diesel	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Heavy-Duty Trucks					
Gas	0.2	0.1	< 0.1	< 0.1	< 0.1
Diesel	0.2	0.2	0.2	0.3	0.3
Off-Road Gasoline	0.2	0.2	0.2	0.2	0.2
Other	0.1	0.2	0.2	0.2	0.2
Fuel Combustion					
Fuelwood	4.5	4.5	4.7	4.9	5.0
Residential/Commercial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	-	-	-	-	-
Plastics	-	-	-	-	-
Crude Oil	-	-	-	-	-
Other	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Incineration/Miscellaneous					
Surface Coatings	1.1	1.2	1.2	1.2	1.3
Fuel Marketing	0.6	0.6	0.6	0.6	0.7
Dry Cleaning	0.1	0.1	0.1	0.1	0.1
Solvent Use	1.3	1.4	1.4	1.5	1.5
Slash Burning	0.2	0.3	0.3	0.3	0.4
Other	0.1	0.1	0.1	0.1	0.1
Power Generation	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
T O T A L	11.0	10.8	10.5	10.7	11.2

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Nova Scotia

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	11.3	8.4	6.1	5.5	5.7
Light-Duty Trucks					
Gas	5.5	4.7	4.1	3.8	3.9
Diesel	0.1	0.1	0.1	0.1	0.1
Heavy-Duty Trucks					
Gas	1.2	0.4	0.2	0.1	0.1
Diesel	1.4	1.7	2.1	2.4	2.8
Off-Road Gasoline	0.9	0.9	0.9	1.0	1.1
Other	2.1	2.3	2.5	2.6	3.0
Fuel Combustion					
Fuelwood	4.6	4.6	4.8	5.0	5.2
Residential/Commercial	0.3	0.3	0.3	0.3	0.3
Industrial	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Industrial Processes					
Petrochemicals	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Petroleum Refining	3.2	3.5	3.6	3.8	4.1
Plastics	0.1	0.1	0.1	0.2	0.2
Crude Oil	0.7	0.5	0.2	0.1	0.1
Other	0.2	0.3	0.3	0.3	0.4
Incineration/Miscellaneous					
Surface Coatings	4.6	5.0	5.2	5.3	5.4
Fuel Marketing	3.7	3.8	3.9	4.0	4.2
Dry Cleaning	0.5	0.5	0.5	0.5	0.5
Solvent Use	9.3	9.6	9.8	10.0	10.1
Slash Burning	2.0	2.6	2.9	3.1	3.4
Other	0.4	0.4	0.4	0.4	0.5
Power Generation	0.1	0.1	0.1	0.1	0.1
T O T A L	52.2	49.8	48.1	48.6	51.3

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: New Brunswick

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	8.9	6.6	4.7	4.2	4.3
Light-Duty Trucks					
Gas	4.5	3.9	3.4	3.1	3.2
Diesel	< 0.1	0.1	0.1	0.1	0.1
Heavy-Duty Trucks					
Gas	1.0	0.3	0.1	0.1	0.1
Diesel	1.0	1.2	1.5	1.7	1.9
Off-Road Gasoline	0.8	0.8	0.8	0.9	0.9
Other	1.4	1.6	1.6	1.7	2.0
Fuel Combustion					
Fuelwood	5.3	5.2	5.5	5.7	5.9
Residential/Commercial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial	< 0.1	0.1	0.1	0.1	0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	1.3	1.4	1.4	1.5	1.6
Plastics	0.1	0.2	0.2	0.3	0.3
Crude Oil	0.5	0.5	0.6	0.6	0.6
Other	0.6	0.7	0.8	0.9	1.0
Incineration/Miscellaneous					
Surface Coatings	3.8	4.1	4.3	4.4	4.4
Fuel Marketing	3.2	3.3	3.4	3.5	3.7
Dry Cleaning	0.4	0.4	0.4	0.4	0.5
Solvent Use	7.5	7.8	8.1	8.3	8.5
Slash Burning	4.5	6.3	7.0	7.6	8.1
Other	0.5	0.5	0.6	0.6	0.6
Power Generation	0.1	0.1	0.1	0.1	0.1
T O T A L	45.4	45.1	44.7	45.8	47.9

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Quebec

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	81.9	63.3	46.3	44.0	46.2
Light-Duty Trucks					
Gas	12.2	15.1	14.5	13.4	13.7
Diesel	0.1	0.2	0.2	0.2	0.3
Heavy-Duty Trucks					
Gas	3.6	1.5	0.7	0.5	0.5
Diesel	3.1	4.5	5.2	5.9	6.7
Off-Road Gasoline	4.8	5.0	5.5	5.9	6.4
Other	10.4	10.6	11.1	11.7	12.6
Fuel Combustion					
Fuelwood	39.9	46.7	50.0	51.5	53.5
Residential/Commercial	0.4	0.4	0.4	0.3	0.3
Industrial	0.3	0.3	0.4	0.4	0.4
Industrial Processes					
Petrochemicals	22.2	24.6	27.4	31.5	36.4
Petroleum Refining	7.1	7.5	7.7	8.0	8.4
Plastics	3.5	4.1	5.4	6.6	7.6
Crude Oil	0.7	0.6	0.6	0.6	0.6
Other	8.3	9.1	10.3	11.3	12.7
Incineration/Miscellaneous					
Surface Coatings	48.5	53.9	57.3	60.1	62.5
Fuel Marketing	23.3	23.3	24.9	26.3	27.2
Dry Cleaning	3.6	3.7	3.8	3.8	3.8
Solvent Use	69.1	70.8	72.0	72.3	72.2
Slash Burning	20.2	26.2	30.0	33.9	38.7
Other	8.8	9.2	9.7	10.0	10.5
Power Generation	0.1	0.1	0.1	0.1	0.1
T O T A L	372.1	380.7	383.5	398.3	421.3

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Ontario

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	154.9	129.4	101.3	92.5	97.6
Light-Duty Trucks					
Gas	50.8	50.1	49.1	46.8	49.2
Diesel	0.6	0.8	0.8	1.2	1.6
Heavy-Duty Trucks					
Gas	2.3	0.9	0.6	0.4	0.4
Diesel	8.9	9.6	10.9	12.4	14.3
Off-Road Gasoline	19.4	20.6	22.7	24.2	25.4
Other	21.6	23.1	23.5	23.5	24.3
Fuel Combustion					
Fuelwood	33.9	31.2	33.8	40.4	41.4
Residential/Commercial	1.1	1.1	1.2	1.2	1.3
Industrial	1.1	1.1	1.3	1.4	1.5
Industrial Processes					
Petrochemicals	39.6	42.0	47.2	54.4	62.7
Petroleum Refining	15.4	16.7	18.1	19.1	20.2
Plastics	8.1	9.4	12.4	15.1	17.4
Crude Oil	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Other	30.4	32.7	39.2	45.6	53.3
Incineration/Miscellaneous					
Surface Coatings	83.3	94.6	105.5	116.2	127.0
Fuel Marketing	41.6	44.3	48.8	51.9	54.6
Dry Cleaning	5.0	5.3	5.5	5.6	5.7
Solvent Use	129.6	136.9	141.8	145.2	147.2
Slash Burning	0.5	0.6	0.7	0.8	1.0
Other	4.2	4.6	5.1	5.5	6.0
Power Generation	0.4	0.4	0.4	0.4	0.4
T O T A L	652.7	655.4	669.9	703.8	752.5

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Manitoba

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	22.2	18.5	14.2	11.8	11.5
Light-Duty Trucks					
Gas	9.3	7.3	6.0	5.4	5.6
Diesel	0.1	0.1	0.1	0.2	0.2
Heavy-Duty Trucks					
Gas	1.9	0.8	0.5	0.3	0.3
Diesel	1.8	2.0	2.4	2.8	3.5
Off-Road Gasoline	4.6	4.3	4.3	4.4	4.7
Other	3.9	4.2	4.3	4.6	4.9
Fuel Combustion					
Fuelwood	1.9	1.5	1.5	1.4	1.3
Residential/Commercial	0.3	0.3	0.2	0.2	0.2
Industrial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	-	-	-	-	-
Plastics	0.3	0.4	0.5	0.6	0.7
Crude Oil	0.1	0.1	0.2	0.2	0.1
Other	0.3	0.3	0.4	0.4	0.4
Incineration/Miscellaneous					
Surface Coatings	5.8	6.3	6.4	6.4	6.5
Fuel Marketing	4.6	4.2	4.0	4.1	4.2
Dry Cleaning	0.6	0.6	0.6	0.6	0.6
Solvent Use	11.3	11.8	12.0	12.0	12.0
Slash Burning	1.0	1.4	1.5	1.8	2.0
Other	0.6	0.7	0.7	0.7	0.7
Power Generation	0.4	0.4	0.4	0.4	0.4
T O T A L	71.0	65.2	60.2	58.3	59.8

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: \Saskatchewan

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	17.3	15.9	12.5	10.2	10.7
Light-Duty Trucks					
Gas	13.4	8.7	6.5	5.8	6.0
Diesel	0.1	0.2	0.2	0.2	0.3
Heavy-Duty Trucks					
Gas	3.1	1.1	0.6	0.5	0.5
Diesel	2.6	2.3	2.5	3.0	3.8
Off-Road Gasoline	10.2	9.1	8.6	9.0	9.8
Other	6.0	5.7	6.0	6.5	7.0
Fuel Combustion					
Fuelwood	2.3	2.1	2.2	2.3	2.2
Residential/Commercial	0.3	0.2	0.2	0.2	0.2
Industrial	0.1	0.1	0.1	0.1	0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	1.7	1.6	1.5	1.6	1.8
Plastics	0.1	0.1	0.1	0.1	0.1
Crude Oil	1.9	2.3	2.5	2.6	2.5
Other	0.4	0.4	0.5	0.6	0.7
Incineration/Miscellaneous					
Surface Coatings	5.1	5.4	5.5	5.5	5.4
Fuel Marketing	4.5	4.0	3.7	3.9	4.2
Dry Cleaning	0.6	0.6	0.7	0.7	0.7
Solvent Use	10.8	11.5	12.0	12.4	12.8
Slash Burning	1.7	2.8	3.2	3.6	4.1
Other	0.4	0.4	0.5	0.5	0.5
Power Generation	0.3	0.3	0.3	0.3	0.3
T O T A L	83.9	74.8	69.9	69.6	73.7

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Alberta

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	50.4	34.1	25.6	21.8	22.1
Light-Duty Trucks					
Gas	16.1	15.0	11.4	9.8	10.0
Diesel	0.2	0.2	0.2	0.3	0.4
Heavy-Duty Trucks					
Gas	3.9	1.9	1.1	0.9	1.0
Diesel	3.6	3.7	3.4	3.5	3.9
Off-Road Gasoline	16.9	15.4	14.8	15.4	15.9
Other	12.1	11.7	12.1	12.8	14.0
Fuel Combustion					
Fuelwood	1.5	1.5	1.6	1.7	1.7
Residential/Commercial	1.0	0.9	0.9	1.0	0.9
Industrial	5.3	5.1	5.7	5.9	5.8
Industrial Processes					
Petrochemicals	44.4	46.1	57.8	77.1	105.1
Petroleum Refining	5.3	5.5	5.7	6.0	6.3
Plastics	0.7	0.8	1.1	1.3	1.5
Crude Oil	10.5	10.0	11.2	11.5	11.2
Other	0.5	0.6	0.7	0.8	0.9
Incineration/Miscellaneous					
Surface Coatings	10.7	11.1	11.2	11.5	12.0
Fuel Marketing	12.9	11.7	11.1	11.5	11.8
Dry Cleaning	1.3	1.3	1.4	1.4	1.4
Solvent Use	24.8	25.0	25.8	26.5	27.1
Slash Burning	5.1	7.6	8.8	9.9	11.3
Other	1.4	1.5	1.6	1.6	1.8
Power Generation	0.6	0.6	0.6	0.6	0.6
T O T A L	229.2	211.3	213.8	232.8	266.7

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: British Columbia

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	58.3	52.2	41.5	35.9	35.5
Light-Duty Trucks					
Gas	26.3	19.3	15.4	13.7	14.2
Diesel	0.2	0.4	0.4	0.5	0.6
Heavy-Duty Trucks					
Gas	6.9	2.6	1.5	1.2	1.2
Diesel	5.2	4.2	4.1	4.4	4.9
Off-Road Gasoline	5.2	5.2	5.2	5.4	5.7
Other	11.7	13.3	14.5	15.3	17.0
Fuel Combustion					
Fuelwood	3.8	4.3	4.5	4.6	5.0
Residential/Commercial	0.3	0.3	0.3	0.3	0.3
Industrial	42.7	39.2	44.4	49.3	55.8
Industrial Processes					
Petrochemicals	1.6	1.7	2.0	2.2	2.6
Petroleum Refining	6.3	6.5	6.4	6.5	6.9
Plastics	0.7	0.9	1.1	1.4	1.6
Crude Oil	0.4	0.4	0.5	0.5	0.5
Other	6.0	7.1	9.9	11.2	11.7
Incineration/Miscellaneous					
Surface Coatings	21.5	22.6	23.7	24.4	25.2
Fuel Marketing	12.4	11.6	11.0	11.0	11.4
Dry Cleaning	1.6	1.7	1.7	1.8	1.8
Solvent Use	30.3	32.0	33.1	33.8	34.3
Slash Burning	43.9	40.2	45.4	50.5	57.4
Other	9.1	8.2	9.2	10.2	11.5
Power Generation	0.3	0.3	0.3	0.3	0.3
T O T A L	294.7	274.2	276.1	284.4	305.4

VOC PROJECTIONS
(Kilotonnes)

PROVINCE: Yukon/North West Territories

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	0.7	0.6	0.5	0.4	0.4
Light-Duty Trucks					
Gas	1.1	0.8	0.6	0.6	0.6
Diesel	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Heavy-Duty Trucks					
Gas	0.3	0.1	0.1	0.1	0.1
Diesel	0.3	0.2	0.2	0.2	0.2
Off-Road Gasoline	0.4	0.4	0.4	0.4	0.4
Other	1.0	1.0	1.1	1.2	1.2
Fuel Combustion					
Fuelwood	1.3	1.5	1.6	1.6	1.7
Residential/Commercial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Industrial Processes					
Petrochemicals	-	-	-	-	-
Petroleum Refining	-	-	-	-	-
Plastics	-	-	-	-	-
Crude Oil	0.2	0.5	0.7	1.1	1.7
Other	-	-	-	-	-
Incineration/Miscellaneous					
Surface Coatings	0.3	0.3	0.3	0.3	0.4
Fuel Marketing	0.3	0.3	0.3	0.3	0.3
Dry Cleaning	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Solvent Use	0.8	0.9	0.9	0.9	0.9
Slash Burning	0.1	0.1	0.1	0.1	0.1
Other	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Power Generation	0.2	0.2	0.2	0.2	0.2
T O T A L	7.0	6.8	7.0	7.4	8.3

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: Canada

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	352.0	250.4	169.0	145.4	149.8
Light-Duty Trucks					
Gas	95.4	86.4	78.7	74.9	77.5
Diesel	5.7	6.9	6.9	8.7	10.9
Heavy-Duty Trucks					
Gas	20.9	13.5	8.0	6.3	6.8
Diesel	264.3	322.0	241.2	230.3	254.0
Off-Road Diesel					
Construction	31.3	32.0	36.0	41.7	49.4
Agriculture	53.5	64.8	70.2	74.8	81.0
Railroads	132.1	113.2	114.0	113.0	113.0
Other	145.6	149.7	168.0	180.1	187.0
Other	79.4	82.7	84.0	86.2	90.6
Fuel Combustion					
Residential	41.5	37.3	37.2	37.2	36.9
Commercial	25.8	25.9	27.3	27.8	28.4
Industrial					
Natural Gas	158.8	155.3	152.5	136.0	112.5
Other	119.4	131.8	150.5	163.7	178.9
Power Generation	247.9	287.7	319.2	363.9	351.7
Industrial Processes	89.0	89.9	104.0	119.8	139.7
Incineration/Miscellaneous	24.3	27.2	29.2	31.9	34.6
T O T A L	1886.9	1876.7	1795.9	1841.7	1902.7

NO_X PROJECTIONS

(Kilotonnes)

PROVINCE: Newfoundland

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	4.9	3.1	1.9	1.7	1.8
Light-Duty Trucks					
Gas	2.1	1.8	1.6	1.5	1.6
Diesel	0.1	0.1	0.1	0.2	0.2
Heavy-Duty Trucks					
Gas	0.7	0.4	0.2	0.1	0.1
Diesel	5.6	7.9	6.6	6.5	7.1
Off-Road Diesel					
Construction	0.4	0.2	0.4	0.4	0.4
Agriculture	0.1	0.1	0.1	0.1	0.2
Railroads	0.8	-	-	-	-
Other	5.8	6.0	6.9	7.7	8.2
Other	2.6	3.0	3.0	3.1	3.2
Fuel Combustion					
Residential	0.8	0.8	0.8	0.8	0.8
Commercial	0.4	0.4	0.3	0.3	0.3
Industrial					
Natural Gas	-	-	-	-	-
Other	2.4	3.2	3.3	3.7	4.3
Power Generation	5.3	6.0	5.6	5.8	5.8
Industrial Processes	1.3	1.3	1.6	1.7	1.7
Incineration/Miscellaneous	0.4	0.4	0.5	0.5	0.5
T O T A L	33.7	34.7	32.9	34.1	36.2

NO_X PROJECTIONS

(Kilotonnes)

PROVINCE: Prince Edward Island

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	1.6	1.0	0.6	0.6	0.6
Light-Duty Trucks					
Gas	0.5	0.5	0.4	0.4	0.4
Diesel	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Heavy-Duty Trucks					
Gas	0.2	0.1	0.1	< 0.1	< 0.1
Diesel	1.5	2.1	1.8	1.7	1.9
Off-Road Diesel					
Construction	0.1	0.1	0.2	0.2	0.2
Agriculture	0.3	0.4	0.5	0.6	0.6
Railroads	0.1	0.2	0.1	0.1	0.1
Other	0.3	0.3	0.4	0.4	0.4
Other	0.3	0.3	0.3	0.3	0.3
Fuel Combustion					
Residential	0.4	0.4	0.4	0.4	0.4
Commercial	0.1	0.1	0.1	0.1	0.1
Industrial					
Natural Gas	-	-	-	-	-
Other	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Power Generation	0.1	0.1	0.1	0.1	0.1
Industrial Processes	-	-	-	-	-
Incineration/Miscellaneous	0.1	0.1	0.1	0.1	0.1
T O T A L	5.6	5.7	5.1	5.0	5.4

NO_X PROJECTIONS

(Kilotonnes)

PROVINCE: Nova Scotia

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	10.6	6.8	4.2	3.7	3.9
Light-Duty Trucks					
Gas	4.0	3.4	3.1	2.9	3.0
Diesel	0.2	0.3	0.3	0.3	0.4
Heavy-Duty Trucks					
Gas	1.1	0.6	0.3	0.2	0.2
Diesel	12.8	18.2	15.2	14.9	16.4
Off-Road Diesel					
Construction	0.7	0.6	0.6	0.7	0.8
Agriculture	0.7	1.0	1.2	1.4	1.6
Railroads	4.1	5.2	5.2	5.2	5.2
Other	8.3	8.4	9.8	10.9	11.6
Other	2.1	2.4	2.5	2.5	2.6
Fuel Combustion					
Residential	1.8	1.8	1.7	1.6	1.6
Commercial	1.2	1.0	0.9	0.9	0.8
Industrial					
Natural Gas	-	-	-	-	-
Other	2.9	3.4	3.6	4.0	4.6
Power Generation	21.7	25.2	26.7	26.8	27.1
Industrial Processes	1.6	1.7	1.8	2.0	2.1
Incineration/Miscellaneous	0.5	0.7	0.7	0.8	0.9
T O T A L	74.3	80.7	77.8	78.8	82.8

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: New Brunswick

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	8.3	5.3	3.3	2.9	3.0
Light-Duty Trucks					
Gas	3.3	2.8	2.5	2.4	2.4
Diesel	0.2	0.2	0.2	0.3	0.3
Heavy-Duty Trucks					
Gas	0.9	0.5	0.2	0.2	0.1
Diesel	8.8	12.5	10.4	10.3	11.3
Off-Road Diesel					
Construction	0.5	0.6	0.6	0.6	0.7
Agriculture	0.5	0.7	0.9	1.0	1.2
Railroads	2.4	3.1	3.1	3.1	3.1
Other	3.5	3.6	4.1	4.6	4.9
Other	0.8	0.8	0.8	0.8	0.9
Fuel Combustion					
Residential	1.0	1.0	1.0	1.0	1.0
Commercial	0.6	0.5	0.5	0.5	0.4
Industrial					
Natural Gas	-	-	-	-	-
Other	3.9	4.8	5.0	5.5	6.3
Power Generation	7.9	22.7	31.6	36.7	39.2
Industrial Processes	2.7	3.1	3.4	3.7	4.0
Incineration/Miscellaneous	1.1	1.5	1.6	1.8	1.9
T O T A L	46.4	63.7	69.2	75.4	80.7

NO_x PROJECTIONS

PROVINCE: Quebec

(Kilotonnes)

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	72.6	50.3	32.7	30.5	32.4
Light-Duty Trucks					
Gas	8.5	11.0	10.8	10.4	10.6
Diesel	0.5	0.6	0.6	0.7	0.9
Heavy-Duty Trucks					
Gas	3.1	2.1	1.1	0.9	0.9
Diesel	28.7	47.9	37.1	35.9	39.1
Off-Road Diesel					
Construction	3.6	4.3	4.9	5.2	5.5
Agriculture	4.4	5.4	5.8	6.2	6.7
Railroads	16.9	11.5	11.6	11.4	11.4
Other	21.1	24.6	26.3	27.5	28.1
Other	16.4	17.3	17.9	18.6	19.9
Fuel Combustion					
Residential	7.5	6.1	5.3	4.5	4.1
Commercial	3.9	4.7	4.7	4.6	4.6
Industrial					
Natural Gas	-	-	-	-	-
Other	21.3	24.6	26.0	28.0	29.4
Power Generation	1.5	1.9	3.3	3.3	3.3
Industrial Processes	6.8	7.8	8.8	10.0	11.3
Incineration/Miscellaneous	6.0	7.3	8.2	9.0	10.1
T O T A L	222.8	227.4	205.1	206.7	218.3

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: Ontario

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	134.4	95.3	65.0	56.7	59.6
Light-Duty Trucks					
Gas	33.0	32.4	32.6	31.9	33.4
Diesel	2.3	2.8	2.8	3.5	4.5
Heavy-Duty Trucks					
Gas	2.0	1.2	0.7	0.7	0.7
Diesel	82.6	102.4	78.7	75.8	83.2
Off-Road Diesel					
Construction	9.1	10.9	13.7	17.1	21.5
Agriculture	7.4	7.5	8.0	8.2	8.6
Railroads	30.3	26.0	26.3	26.0	26.0
Other	27.2	31.7	34.7	34.9	34.3
Other	20.2	22.0	23.1	23.7	24.4
Fuel Combustion					
Residential	15.4	14.6	15.0	15.4	15.3
Commercial	9.7	9.5	10.4	10.5	11.0
Industrial					
Natural Gas	0.5	0.5	0.6	0.6	0.6
Other	45.1	50.1	58.2	63.7	70.5
Power Generation	97.6	74.9	83.4	114.6	94.8
Industrial Processes	38.2	40.5	47.6	54.2	62.3
Incineration/Miscellaneous	2.5	2.7	2.8	2.9	2.9
T O T A L	557.5	525.0	503.6	540.4	553.6

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: Manitoba

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	17.1	12.7	8.7	7.1	6.9
Light-Duty Trucks					
Gas	6.1	4.8	4.0	3.7	3.9
Diesel	0.3	0.4	0.4	0.5	0.6
Heavy-Duty Trucks					
Gas	1.7	1.1	0.7	0.5	0.5
Diesel	16.2	21.1	17.2	17.4	20.2
Off-Road Diesel					
Construction	1.4	1.9	1.9	2.2	2.6
Agriculture	5.2	6.1	7.0	7.0	7.2
Railroads	17.2	15.4	15.5	15.4	15.4
Other	3.7	5.7	6.3	6.6	7.0
Other	4.3	4.3	4.3	4.4	4.6
Fuel Combustion					
Residential	1.5	1.3	1.3	1.3	1.3
Commercial	1.3	1.2	1.3	1.4	1.4
Industrial					
Natural Gas	-	-	-	-	-
Other	2.2	2.2	2.5	2.8	3.3
Power Generation	2.7	1.6	1.6	0.7	0.7
Industrial Processes	0.6	0.6	0.7	0.8	0.9
Incineration/Miscellaneous	0.4	0.4	0.4	0.5	0.5
T O T A L	81.9	80.8	73.8	72.3	77.0

NO_X PROJECTIONS

(Kilotonnes)

PROVINCE: Saskatchewan

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	13.1	10.8	7.6	6.1	6.4
Light-Duty Trucks					
Gas	8.7	5.6	4.3	4.0	4.1
Diesel	0.4	0.6	0.6	0.7	0.9
Heavy-Duty Trucks					
Gas	2.7	1.6	0.9	0.7	0.8
Diesel	24.1	24.1	18.3	18.3	22.0
Off-Road Diesel					
Construction	2.6	2.5	2.6	2.9	3.4
Agriculture	14.9	17.6	19.0	21.0	23.5
Railroads	9.6	6.9	6.9	6.9	6.9
Other	7.4	8.5	9.6	10.3	10.4
Other	9.5	8.6	8.1	8.1	8.7
Fuel Combustion					
Residential	2.3	2.0	2.1	2.2	2.2
Commercial	1.1	1.1	1.3	1.4	1.5
Industrial					
Natural Gas	16.9	19.6	21.5	22.2	22.1
Other	4.8	4.5	5.1	5.8	6.4
Power Generation	36.1	43.6	47.8	45.6	44.0
Industrial Processes	0.9	1.0	1.1	1.2	1.4
Incineration/Miscellaneous	0.5	0.6	0.7	0.8	0.8
T O T A L	155.6	159.2	157.5	158.2	165.5

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: Alberta

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	42.3	27.2	18.6	15.5	15.6
Light-Duty Trucks					
Gas	11.2	10.9	8.5	7.7	7.8
Diesel	0.6	0.7	0.7	0.9	1.1
Heavy-Duty Trucks					
Gas	3.5	2.9	1.8	1.5	1.8
Diesel	33.5	39.5	24.7	21.4	22.7
Off-Road Diesel					
Construction	8.1	6.3	6.4	7.4	8.8
Agriculture	17.1	20.6	21.1	22.3	24.0
Railroads	33.8	31.4	31.7	31.4	31.4
Other	25.2	21.9	26.0	29.5	30.9
Other	14.9	13.8	13.5	13.9	14.5
Fuel Combustion					
Residential	7.0	5.9	6.2	6.5	6.6
Commercial	4.5	4.5	4.8	5.1	5.2
Industrial					
Natural Gas	131.5	124.9	118.4	100.3	76.7
Other	11.3	13.8	18.0	18.4	19.0
Power Generation	68.1	106.3	112.7	122.4	127.0
Industrial Processes	26.2	21.8	25.6	31.3	39.3
Incineration/Miscellaneous	1.5	2.4	2.6	2.9	3.2
T O T A L	440.3	454.8	441.3	438.4	435.6

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: British Columbia

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	46.6	37.5	26.1	20.4	19.4
Light-Duty Trucks					
Gas	17.3	12.7	10.5	9.6	9.9
Diesel	0.9	1.2	1.2	1.5	1.8
Heavy-Duty Trucks					
Gas	4.8	2.9	1.9	1.6	1.6
Diesel	48.2	44.2	29.8	26.8	28.7
Off-Road Diesel					
Construction	4.0	3.7	3.7	3.9	4.2
Agriculture	2.9	5.3	6.5	6.9	7.3
Railroads	16.8	13.4	13.5	13.4	13.4
Other	37.2	33.7	37.9	41.2	44.2
Other	6.7	8.2	8.4	8.6	9.2
Fuel Combustion					
Residential	3.6	3.2	3.2	3.3	3.3
Commercial	2.7	2.6	2.8	2.8	2.9
Industrial					
Natural Gas	9.9	10.3	12.0	12.9	13.1
Other	25.3	25.1	28.7	31.6	34.8
Power Generation	3.7	1.0	1.0	1.0	1.2
Industrial Processes	10.7	12.1	13.4	14.9	16.7
Incineration/Miscellaneous	11.3	11.1	11.6	12.6	13.7
T O T A L	252.6	228.2	212.2	213.0	225.4

NO_x PROJECTIONS

(Kilotonnes)

PROVINCE: Yukon/North West Territories

SECTOR	1985	1990	1995	2000	2005
Transportation					
Cars	0.5	0.4	0.3	0.2	0.2
Light-Duty Trucks					
Gas	0.7	0.5	0.4	0.4	0.4
Diesel	< 0.1	< 0.1	< 0.1	0.1	0.1
Heavy-Duty Trucks					
Gas	0.2	0.1	0.1	0.1	0.1
Diesel	2.3	2.1	1.4	1.3	1.4
Off-Road Diesel					
Construction	0.8	0.9	1.0	1.1	1.3
Agriculture	< 0.1	0.1	0.1	0.1	0.1
Railroads	0.1	0.1	0.1	0.1	0.1
Other	5.9	5.3	6.0	6.5	7.0
Other	1.6	2.0	2.1	2.2	2.3
Fuel Combustion					
Residential	0.2	0.2	0.2	0.2	0.2
Commercial	0.3	0.3	0.2	0.2	0.2
Industrial					
Natural Gas	-	-	-	-	-
Other	0.2	0.1	0.1	0.2	0.2
Power Generation	3.2	4.4	5.4	6.9	8.5
Industrial Processes	-	-	-	-	-
Incineration/Miscellaneous	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
T O T A L	16.0	16.6	17.5	19.6	22.1

Preparation of a Canadian Inventory of Biogenic Volatile Organic Carbon Emissions from Vegetation

A Report to:

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Preparation of a Canadian Inventory of Biogenic Volatile Organic Carbon Emissions from Vegetation

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SUMMARY

A Canadian inventory of biogenic VOC emissions from canopy and non-canopy vegetation has been prepared for the years 1985 and 1988. The methodology used for the Eulerian Model Evaluation Field Study (EMEFS) was also used for this study. Canopy emissions were estimated using an eight-layered canopy model developed by B. Lamb at Washington State University, 1989. Emission factors at a standard temperature of 30°C for isoprene, alpha-pinene, other mono-terpenes and other unknown hydrocarbons were corrected using hourly temperature, wind, humidity and cloud data for thirty-three climate zones. The hourly zonal factors were averaged to produce monthly averages. These monthly emission factors were applied to monthly biomass estimates on a 127 x 127 km grid to obtain Canadian and provincial annual and seasonal emissions for 1985 and 1988. Total biogenic VOC emissions were 11.1 and 11.9 million tonnes in 1985 and 1988, respectively. The summer season accounts for approximately 53 percent of the emissions. On an annual basis, isoprene accounts for 12 percent, alpha-pinene and other mono-terpenes each for 25 percent, with the balance of 38 percent being made up of unknown hydrocarbons.

1. INTRODUCTION

ORTECH International ,under contract to Environment Canada, has prepared a biogenic volatile organic carbon emissions inventory for the Eulerian Model Evaluation Field Study project (EMEFS). For EMEFS, the inventory was prepared for the first intensive study period of approximately 90 days and hourly emissions were generated on the 127 km OME grid for the ADOM model. Meteorological data were used to generate hour specific emission factors for iso-prene, alpha-pinene, other mono-terpenes and other unidentified hydrocarbons. The methodology used was developed by the U.S. EPA for EMEFS and is based on Tingey, 1981, and B. Lamb of Washington State University, 1988. As a second part to this study, Environment Canada has contracted ORTECH International to prepare a biogenic VOC emissions inventory for Canada on a seasonal as well as a regional (or provincial) basis. This report deals only with this second part of the contract.

The same methodology as was used for EMEFS was used for the Canada-wide inventory, except that hourly observational data were used on a climate zone basis rather than on a 127 km grid. Figure 1.1 shows the climate zones used in this study. These data were used to compute zonal monthly average emission factors using an eight-layer canopy emissions model and a single-layer non-canopy model for the selected years 1985 and 1988. A full inventory of anthropogenic sources also exists for the base year 1985. Since the gridded information provided for preparing the EMEFS files only extends to longitude 125 degrees west and latitude 60 degrees north, it was necessary for this study to expand the longitude coverage by 15 degrees so as to include all of British Columbia, and to extend the latitude coverage to 70 degrees north to include the biomass in the Yukon and Northwest Territories.

2. METHODOLOGY

2.1 Computation of Emission Factors

For the EMEFS biogenic VOC inventory, the U.S. EPA has gridded the canopy and non-canopy biomass densities onto the 1/6 x 1/4 degree NAPAP lat/lon grid which extends from 50 to 125 degrees west and from 40 to 60 degrees north. In addition, monthly gridded files were provided which contain a zero or one for each grid, depending on whether climatological records show the occurrence of frost in that month. The occurrence of frost in a specific grid is taken to infer that the month is in the non-growing season and emissions from deciduous canopy and non-canopy vegetation are zero. Emission factors at a standard temperature of 30°C for the various canopy and non-canopy vegetation classes were corrected for the effects of leaf temperature and actinic solar flux using algorithms provided for EMEFS. For non-canopy biomass, the leaf temperature is assumed to be equal to the air temperature. For the canopy biomass, an energy balance is carried out on the leaf surfaces in eight canopy layers to determine the leaf temperature.

The overall methodology used to compute the biogenic emissions for EMEFS was provided by Galluppi, private communication (1989). This documentation deals only with the single layer canopy model. The multi-layer model was provided for EMEFS in the form of computer code and specific documentation on the multi-layered model is not available. In essence, the layered model is similar to the unlayered model, except that each layer is computed separately using layer estimates of leaf temperature and solar intensity as is briefly described below. An appendix to this report provides further details of the single layer model taken from Galluppi (1989). The canopy model energy balance has the following components in each layer:

- incoming solar radiation corrected for canopy interception by higher layers
- longwave ground radiation corrected for interception by lower layers
- radiative cooling of the leaf
- sensible heat transfer to the leaf using an aerodynamic transfer coefficient which depends on leaf type and wind speed profile
- latent heat transfer from the leaf which depends on the humidity above and within the canopy.

The vertical distribution of biomass within the canopy depends on the canopy type. Profiles of wind, temperature and humidity are specified within the canopy. The energy balance is solved iteratively for the leaf temperature which is then used in the temperature adjustment algorithm.

The correction algorithms are of exponential form and are, therefore, highly non-linear in both temperature and solar flux. For the preparation of an annual inventory, which is resolved both seasonally and regionally, it was necessary to compute seasonal and annual average emission factors for the biogenic VOC's for approximately thirty-three climate zones (see Figure 1.1). These averages were computed from hourly cloud, temperature, wind and humidity data for a climate station in each zone. The mean emission factors were then gridded onto a 127 km polar-stereographic grid by applying the zonal emission factors to all grids in the climate zone.

2.2 Extension of Grid to 140 Degrees West and 70 Degrees North

For the EMEFS, the NAPAP grid coverage was extended by the U.S. EPA from 55 to 60 degrees north using the vegetation and land-use data of Matthews, 1984a, which provides global coverage on a 1 x 1 degree lat/long grid. Matthews was also used for this study to further extend the grid to 140 degrees west and 70 north. This domain includes all the significant biomass

for VOC emissions. The land-use data were extracted from Matthews' data base and entered into the extended 1/4 x 1/6 degree grid. All twenty-four grids, making up the one degree Matthews grid, were assigned the same vegetation and land-use. The biomass data on the augmented NAPAP grid were agglomerated to the 127 km polar-stereographic grid by centroid.

First and last frost flags were generated for 1985 and 1988 from the hourly zonal meteorological data based on first and last occurrence of a zero degree temperature.

The Matthews data base provides 32 UNESCO vegetation types. Matthews, 1984b, provides a scheme to aggregate these classes into nine vegetation types which include deciduous and evergreen forest as well as grasslands. Using this aggregation scheme, the biomass density for the various land-use classes was estimated.

2.3 Computation of the Emissions Inventory

The Environment Canada climate archives were scanned for observing stations which report hourly data in each climate zone. A station was selected in each zone to represent the entire zone and the hourly data for cloud, temperature, wind and humidity were extracted for the years 1985 and 1988. Table 2.1 lists the stations used for each zone. For some zones, no complete hourly station record existed and data from the same latitude zone in an adjacent province was used.

The correction algorithms for biogenic VOC emission require both the temperature and actinic solar flux as input parameters. The canopy model also requires the energetic solar flux for the energy balance. Using the station location, time and cloud data, the hourly actinic and energetic solar fluxes were calculated based on the zenith angle of the sun, using algorithms provided for the EMEFS study.

The solar flux together with the hourly temperature, wind and humidity were used to calculate an hour-by-hour emission factor for emitters of iso-prene, alpha-pinene, other monoterpenes and other unidentified hydrocarbons, using the EMEFS canopy model and temperature correction algorithms. The hourly factors were averaged over each month to produce a monthly average emission factor for each biomass class. These averaged factors were used as an estimate for all grids within the climate zone in which the observing station lies.

Finally, the gridded monthly canopy and non-canopy biomass densities were multiplied by the average emission factors to produce a monthly gridded emissions inventory for the four VOC classes. National and provincial total biogenic emissions were obtained by summation of 127 km gridded emissions. Where the grids straddled provincial or international boundaries, the emissions were apportioned according to area.

3. DISCUSSION

Figures 3.1 and 3.2 show the Canadian total biogenic emissions of isoprene, alpha-pinene, other monoterpenes and other unknown hydrocarbons from the canopy and non-canopy vegetation, for 1985 and 1988. The numerical data for these plots are provided in Tables 3.1 and 3.2, and it is seen that the differences in the total emissions between these two years is approximately 8 percent with 11.1 million tonnes total VOC emitted in 1985, compared to 11.9 million tonnes in 1988. The contributions of the provinces to the seasonal totals (Figures 3.3, 3.4 and Tables 3.3, 3.4) are also quite similar for these two years with a trend to slightly higher emissions in 1988 for Quebec, Ontario, Manitoba and Saskatchewan. Approximately 53 percent of the emissions are during the summer season, 20 percent during each of spring and fall, and 7 percent in winter. On an annual basis, isoprene accounts for 12 percent, alpha-pinene and other monoterpenes each for 25 percent, with unspecified hydrocarbons making up the balance

of 38 percent. Isoprene emissions and the major proportion of unspecified hydrocarbons are due to deciduous vegetation, particularly oak, while alpha-pinene and mono-terpenes are mainly emitted by conifers, with a minor contribution from deciduous vegetation. Figures 3.5 and 3.6 show the provincial contributions to these four biogenic VOC classes.

From the viewpoint of atmospheric chemistry, the reactivity of the biogenic hydrocarbons is of importance. In the chemistry scheme used by the ADOM Eulerian model, the isoprene is considered as a separate reactive class, while the alpha-pinene and other mono-terpenes are included with the alkenes. In addition, 25 percent of the unknown hydrocarbons emissions are considered to be reactive alkenes. On this basis, the following comparison with 1985 anthropogenic VOC emissions can be made for Canada and the U.S.:

	Isoprene	Alkenes (megatonnes)	Total VOC
Canada:			
vegetation	1.35	6.63	11.1
anthropogenic	0.0	-	1.8
			12.9
U.S.:			
vegetation	4.6	-	30.7
anthropogenic	0.0	-	20.0
			50.7

This table shows that the anthropogenic emissions constitute 14 percent of the total VOC in Canada and 39 percent in the U.S. On a flux basis, however, in urban areas where most of the other chemical reactants are emitted, the emission flux of natural VOC would be very much smaller than that from anthropogenic sources. Some of the natural VOC would mix and react with anthropogenic emissions in urban plumes, while the major portion would only encounter urban emissions through much slower

regional mixing. It is anticipated that biogenic and anthropogenic VOC emissions would play somewhat different roles in the overall regional atmospheric chemistry.

Tables 3.5 and 3.6 and Figures 3.7 and 3.8. provide the annual zonal emissions of biogenic VOC for 1985 and 1988. Climate zones having no significant biomass (tundra for example) are omitted from the tables.

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TABLE 2.1: CLIMATE ZONE OBSERVING STATIONS

te	Observing Station Used	Stn. No.	Lat.	Lon.
	NFLD: GANDER A	8401700	48.95	-54.62
	NFLD: DEER LAKE A	8401501	49.22	-57.40
	NOVA SCOTIA: SYDNEY A	8205700	46.17	-60.05
	NOVA SCOTIA: SYDNEY A	8205700	46.17	-60.05
	NEW BRUNSWICK: FREDERICTON A	8101500	45.87	-66.53
	QUEBEC: MIRABEL A	7035290	45.68	-74.03
	QUEBEC: CHIBOUGAMAU-CHAPAIS A	7091404	49.77	-74.53
	QUEBEC: SCHEFFERVILLE A	7117825	54.80	-66.82
	QUEBEC: KUUJJUAQ A	7113534	58.10	-68.42
	ONTARIO: LONDON A	6144475	43.03	-81.15
	ONTARIO: SUDBURY A	6068250	46.62	-80.80
	ONTARIO: GERALDTON A	6042716	49.78	-86.93
	ONTARIO: BIG TROUT LAKE	6010733	53.83	-89.87
	MANITOBA: WINNIPEG A	5023222	49.90	-97.23
	MANITOBA: THE PAS A	5052880	53.97	-101.10
	MANITOBA: LYNN LAKE A	5061646	56.87	-101.08
	SASKATCHEWAN: REGINA A	4016560	50.43	-104.67
	SASKATCHEWAN: LA RONGE A	4064150	55.15	-105.27
	ALBERTA: HIGH LEVEL	3073146	58.62	-117.17
	ALBERTA: LETHBRIDGE A	3033880	49.63	-112.80
	ALBERTA: GRANDE PRAIRIE A	3072920	55.18	-118.88
	ALBERTA: HIGH LEVEL	3073146	58.62	-117.17
	BRITISH COLUMBIA: CRANBROOK A	1152102	49.60	-115.78
	BRITISH COLUMBIA: PRINCE GEORGE A	1096450	53.88	-122.68
	BRITISH COLUMBIA: FORT NELSON A	1192940	58.83	-122.58
	MANITOBA: CHURCHILL A	5060600	58.75	-94.07
	NORTHWEST TERRITORIES: FORT SIMPSON A	2202101	61.75	-121.23
	NORTHWEST TERRITORIES: FORT SIMPSON A	2202101	61.75	-121.23
	NORTHWEST TERRITORIES: HALL BEACH A	2402350	68.78	-81.25
	NORTHWEST TERRITORIES: INUVIK A	2202570	68.30	-133.48
	NORTHWEST TERRITORIES: FORT SIMPSON A	2202101	61.75	-121.23

TABLE 3.1: 1985 PROVINCIAL TOTALS

PROVINCE	ISOP	ALPHA	MONO	OTHER	TOT. VOC
NFLD	84179	134327	135974	161956	516436
PEI	1125	2039	2003	3318	8485
NS	20067	37158	36329	89717	183271
NB	12196	20971	20749	34591	88507
PQ	292119	596315	576995	869842	2335272
ONT	180257	393412	381474	606863	1562006
MAN	120350	249979	242552	357129	970010
SASK	78088	161004	156025	232262	627380
ALB	138322	208630	204253	347005	898210
BC	238855	568054	557981	792838	2157728
NWT	133827	297746	285945	402773	1120290
YUK	47695	109799	105779	148794	412067
TOTALS	1347081	2839434	2756059	4117089	

TOTAL YEARLY VOC **1.11E+07**

TABLE 3.2: 1988 PROVINCIAL TOTALS

PROVINCE	ISOP	ALPHA	MONO	OTHER	TOT. VOC
NFLD	82140	138045	139825	267446	627456
PEI	1153	2092	2056	3450	8751
NS	19716	37960	37117	61031	155824
NB	13303	21636	21427	36927	93294
PQ	296750	613018	595077	900397	2405242
ONT	208050	440125	433113	692923	1774211
MAN	139182	239305	286248	426646	1141381
SASK	84777	177418	173707	263148	699051
ALB	172597	234245	229896	423572	1060309
BC	231733	393320	383061	828200	1836314
NWT	131579	317467	306699	431346	1187091
YUK	46229	115148	111363	156408	429148
TOTALS	1427209	3139780	3069590	4491493	

TOTAL YEARLY VOC 1.19E+07

TABLE 3.3: SEASONAL PROVINCIAL TOTALS FOR 1985

PROVINCE: NEWFOUNDLAND

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	10228	14613	12196	17211	54248
SPRING	25416	34513	31476	44323	135727
SUMMER	83479	98009	88014	138123	407626
FALL	15056	47192	44288	62399	168934
ANNUAL	84179	194327	185974	261956	726436

PROVINCE: PRINCE EDWARD ISLAND

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	103	175	153	214	646
SPRING	192	375	355	501	1423
SUMMER	653	988	1008	1864	4513
FALL	177	501	488	739	1904
ANNUAL	1125	2039	2003	3319	8486

PROVINCE: NOVA SCOTIA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	1895	3508	3073	4322	12798
SPRING	3564	6521	6122	8632	24839
SUMMER	10953	17530	17821	32181	78486
FALL	3655	9598	9313	14582	37148
ANNUAL	20067	37158	36329	59717	153271

PROVINCE: NEW BRUNSWICK

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	1063	1603	1390	1950	6006
SPRING	1961	4116	3950	5572	15600
SUMMER	7746	10407	10681	20402	49237
FALL	1426	4845	4727	6667	17665
ANNUAL	12196	20971	20749	34591	88507

PROVINCE: QUEBEC

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	30669	39265	32611	45694	148239
SPRING	72641	113458	105763	149002	440863
SUMMER	134894	296945	299138	467089	1198065
FALL	53916	146648	139484	208057	548105
ANNUAL	292119	596315	576995	869842	2335272

TABLE 3.3 CONT'D: SEASONAL PROVINCIAL TOTALS FOR 1985

PROVINCE: ONTARIO

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	19344	23267	19240	26947	88799
SPRING	46356	87907	83647	124980	342889
SUMMER	81934	191965	192602	321338	787839
FALL	32623	90273	85985	133598	342479
ANNUAL	180257	393412	381474	606863	1562006

PROVINCE: MANITOBA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	11591	13575	11082	15524	51772
SPRING	32512	60077	57209	80887	230684
SUMMER	58077	127701	128749	196519	511047
FALL	18170	48625	45512	64200	176507
ANNUAL	120350	249979	242552	357129	970010

PROVINCE: SASKATCHEWAN

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	6363	10177	8512	11928	36981
SPRING	21602	40114	38199	55116	155031
SUMMER	39311	81862	82464	127387	331023
FALL	10811	28851	26851	37831	104345
ANNUAL	78088	161004	156025	232262	627380

PROVINCE: ALBERTA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	7262	18405	16175	22704	64546
SPRING	22382	47313	45591	64339	179625
SUMMER	82701	82933	88483	179093	443210
FALL	12165	33523	31379	44187	121253
ANNUAL	134510	182174	181627	310323	808635

PROVINCE: BRITISH COLUMBIA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	20389	52104	45383	63551	181428
SPRING	64989	140149	135261	190789	531188
SUMMER	96375	199293	217344	302112	815123
FALL	37098	100623	94424	132866	365011
ANNUAL	218851	492169	492412	689318	1892749

TABLE 3.3 CONT'D: SEASONAL PROVINCIAL TOTALS FOR 1985

PROVINCE: NORTH WEST TERRITORIES

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	6874	17981	14653	[illegible]	[illegible]
SPRING	45378	63471	59015	[illegible]	[illegible]
SUMMER	54634	114764	121663	[illegible]	[illegible]
FALL	18064	55007	50625	[illegible]	[illegible]
ANNUAL	124650	251223	245956	[illegible]	[illegible]

PROVINCE: YUKON

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	2576	6693	5496	[illegible]	22448
SPRING	15856	24230	22696	31991	94773
SUMMER	25493	42411	44932	61492	174329
FALL	6701	19919	18414	[illegible]	[illegible]
ANNUAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3.4: SEASONAL PROVINCIAL TOTALS FOR 1988

PROVINCE: NEWFOUNDLAND

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	10836	14023	11730	16455	53043
SPRING	24766	42367	39578	55802	162513
SUMMER	32590	95866	95823	135054	359333
FALL	13948	45784	42694	60135	162560
ANNUAL	82140	198045	189825	267446	737455

PROVINCE: PRINCE EDWARD ISLAND

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	102	192	169	237	700
SPRING	184	399	381	537	1501
SUMMER	648	1000	1022	1889	4559
FALL	219	502	484	796	1991
ANNUAL	1153	2092	2056	3460	8751

PROVINCE: NOVA SCOTIA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	1863	3843	3399	4782	13887
SPRING	3397	7205	6841	9654	27097
SUMMER	10595	17432	17729	31991	77748
FALL	3861	9480	9148	14604	37093
ANNUAL	19716	37960	37117	61031	155825

PROVINCE: NEW BRUNSWICK

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	1067	1757	1541	2162	6523
SPRING	1898	4194	4034	5692	15818
SUMMER	7918	10744	11076	21143	50880
FALL	2420	4942	4777	7930	20069
ANNUAL	13303	21636	21427	36927	93294

PROVINCE: QUEBEC

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	31714	40015	33496	46948	152173
SPRING	80658	134386	127310	190630	532984
SUMMER	143325	306192	310048	487243	1246808
FALL	41053	132425	124223	175576	473276
ANNUAL	296750	613018	595077	900397	2405242

TABLE 3.4 CONT'D: SEASONAL PROVINCIAL TOTALS FOR 1988

PROVINCE: ONTARIO

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	21141	24541	20503	28761	[illegible]
SPRING	48384	89611	85960	128382	[illegible]
SUMMER	107891	235514	241056	403302	[illegible]
FALL	30634	80459	85539	132478	[illegible]
ANNUAL	208050	440125	433113	692923	[illegible]

PROVINCE: MANITOBA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	11831	14550	12025	16855	55261
SPRING	33523	58849	56445	79702	228519
SUMMER	73942	157665	162442	250087	644136
FALL	19886	58241	55335	80003	213465
ANNUAL	139182	289305	286248	426646	1141381

PROVINCE: SASKATCHIWAN

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	6438	10588	8912	12491	[illegible]
SPRING	19687	37432	35687	50366	[illegible]
SUMMER	47460	94442	95938	153523	[illegible]
FALL	11192	34955	33171	46768	[illegible]
ANNUAL	84777	177418	173707	263148	[illegible]

PROVINCE: ALBERTA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	7465	17916	15738	22096	[illegible]
SPRING	21939	49788	47975	67982	[illegible]
SUMMER	93915	82380	85998	183959	[illegible]
FALL	14916	45739	44192	62541	[illegible]
ANNUAL	138235	195824	193904	336577	[illegible]

PROVINCE: BRITISH COLUMBIA

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	22817	53064	46479	65164	[illegible]
SPRING	61091	140274	134995	190454	[illegible]
SUMMER	77035	182183	193692	268947	[illegible]
FALL	43640	132583	128170	180566	484959
ANNUAL	204582	508104	503336	705131	1921153

TABLE 3.4 CONT'D: SEASONAL PROVINICIAL TOTALS FOR 1988

PROVINCE: NORTH WEST TERRITORIES

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	7152	16584	13368	18656	55759
SPRING	43476	64516	59767	84196	251955
SUMMER	83133	123935	128343	177716	483127
FALL	18311	56869	52729	74213	202122
ANNUAL	152072	261904	254207	354780	992963

PROVINCE: YUKON

SEASON	ISOP	ALPHA	MONO	OTHER	TOT. VOC
WINTER	2883	6024	4882	6814	20603
SPRING	14869	24094	22448	31628	93038
SUMMER	24340	44073	45440	62742	176596
FALL	6770	20817	19396	27301	74285
ANNUAL	48862	95008	92166	128485	364521

TABLE 3.5: EMISSIONS BY CLIMATE ZONE FOR1985

Tonnes (t)

Climate Zone	Isoprene	Alpha-Pinene	Mono-Terpenes	Others	NO	NO2	Total VOC
11	[illegible]	19403	23214	39584	[illegible]	[illegible]	[illegible]
12	8148	21048	20420	28786	[illegible]	[illegible]	78301
13	[illegible]	13915	13561	22792	[illegible]	[illegible]	58075
14	8146	16139	15727	25491	0.0	[illegible]	65703
21	28836	32868	32519	53889	[illegible]	[illegible]	[illegible]
31	108419	187094	184718	312850	[illegible]	0.6	793081
32	160036	352278	339779	480289	0.0	0.0	1322452
33	37152	178143	168155	237162	[illegible]	[illegible]	670513
34	[illegible]	15301	14412	20332	[illegible]	0.0	87179
41	[illegible]	10655	10222	55911	[illegible]	[illegible]	84301
42	59464	114211	112249	181963	[illegible]	[illegible]	467897
43	95780	210075	202925	288464	[illegible]	[illegible]	797243
44	[illegible]	44172	42095	61045	[illegible]	[illegible]	168813
[illegible]	[illegible]	58182	57227	89868	[illegible]	[illegible]	225883
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3.6: EMISSIONS BY CLIMATE ZONE FOR 1988

Tonnes (C)

Climate Zone	Isoprene	Alpha-Pinene	Mono-Terpenes	Others	NO	NO2	Total VOC
11	10773	11617	29518	41509	0.1	[illegible]	112417
12	7864	21948	21309	30009	0.0	[illegible]	81130
21	7449	14179	13817	23017	0.0	[illegible]	58462
22	7974	16462	16040	25809	0.0	[illegible]	66286
41	20496	33888	33559	57432	0.9	[illegible]	145375
31	117336	183451	191925	327482	7.6	[illegible]	830194
32	145485	271559	359084	607664	0.0	[illegible]	1382792
33	84900	172260	161851	228242	0.0	[illegible]	647253
34	7118	14378	13412	19909	0.0	[illegible]	53816
51	9940	11652	11316	62564	10.3	[illegible]	95473
52	68289	123405	122783	200806	2.4	[illegible]	515283
53	97491	234551	230090	329532	3.5	[illegible]	890665
54	24553	52783	51083	75532	0.0	[illegible]	203950
71	43877	72684	73413	118836	30.7	[illegible]	308810
72	56897	151632	149302	218409	0.0	[illegible]	585240
73	31726	78947	77260	113341	0.0	[illegible]	299274
74	14319	18807	18464	18585	193.3	[illegible]	70376
42	89698	188679	191044	196257	0.0	[illegible]	665678
43	12481	28354	31233	44121	0.0	[illegible]	116250
91	16750	41452	41049	89553	270.3	[illegible]	188805
92	89397	208394	200222	230881	0.0	[illegible]	732894
93	48707	48627	47236	102950	1.8	[illegible]	247521
101	135204	313879	319236	459597	37.2	[illegible]	1233916
102	79772	221642	213705	301446	58.8	[illegible]	815565
103	55989	148242	141554	199940	120.8	[illegible]	543724
111	0	0	0	0	0.0	0.0	0
112	1156	2332	2840	3986	6.7	0.6	10914
113	80151	202770	195679	275294	252.1	23.2	752894
114	0	0	0	0	0.0	0.0	0
115	32899	69384	66237	93029	110.0	10.1	261548
117	514	1083	1034	1452	1.8	0.2	4084
121	39545	100016	96931	136137	195.0	17.9	372630
122	9555	18030	17214	24182	26.8	2.5	67981
TOTALS	1427215	3039789	2969599	4491502	1337.5	123.0	

TOTAL VOC: 1.19E+07

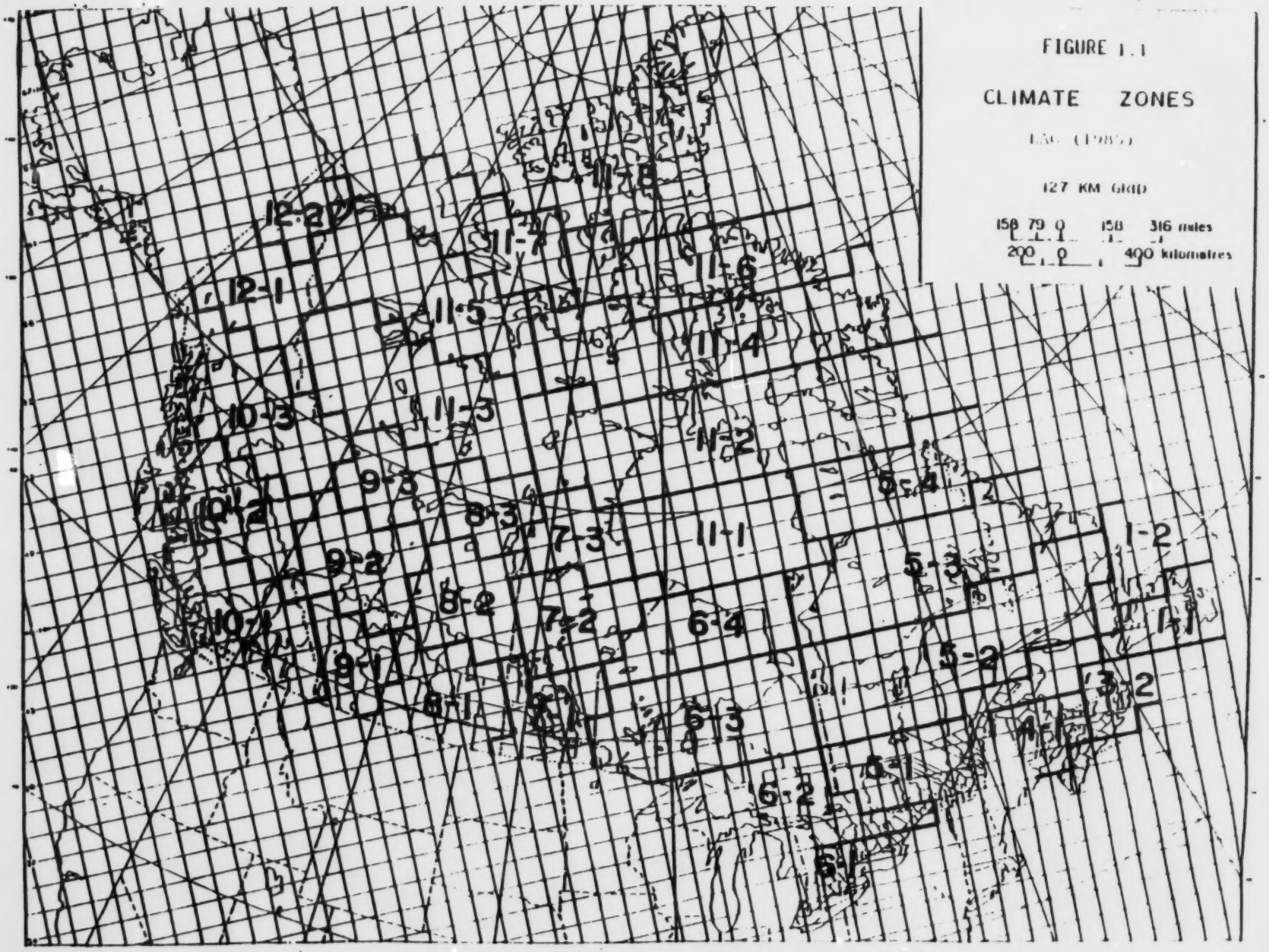


FIGURE 1.1

CLIMATE ZONES

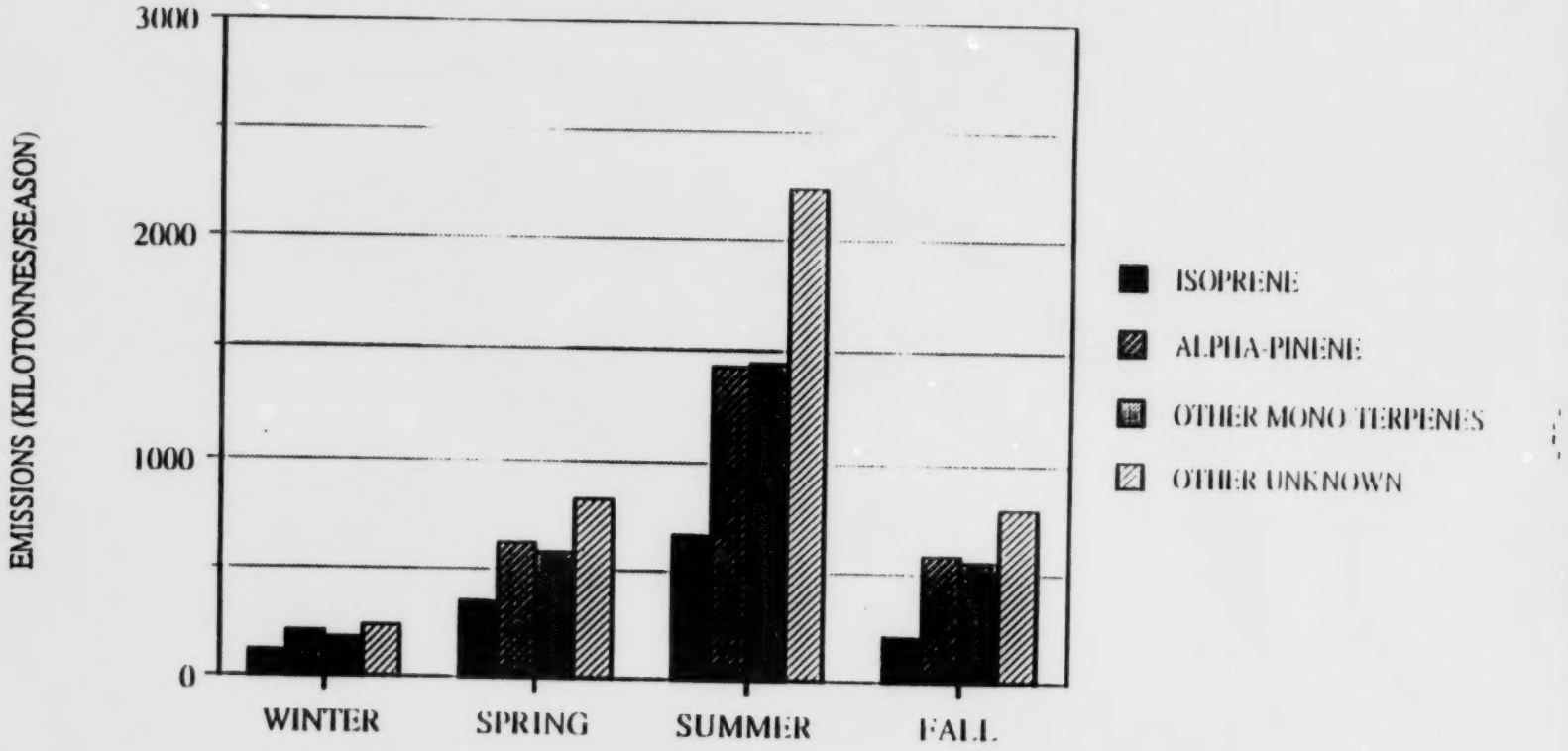
[illegible]

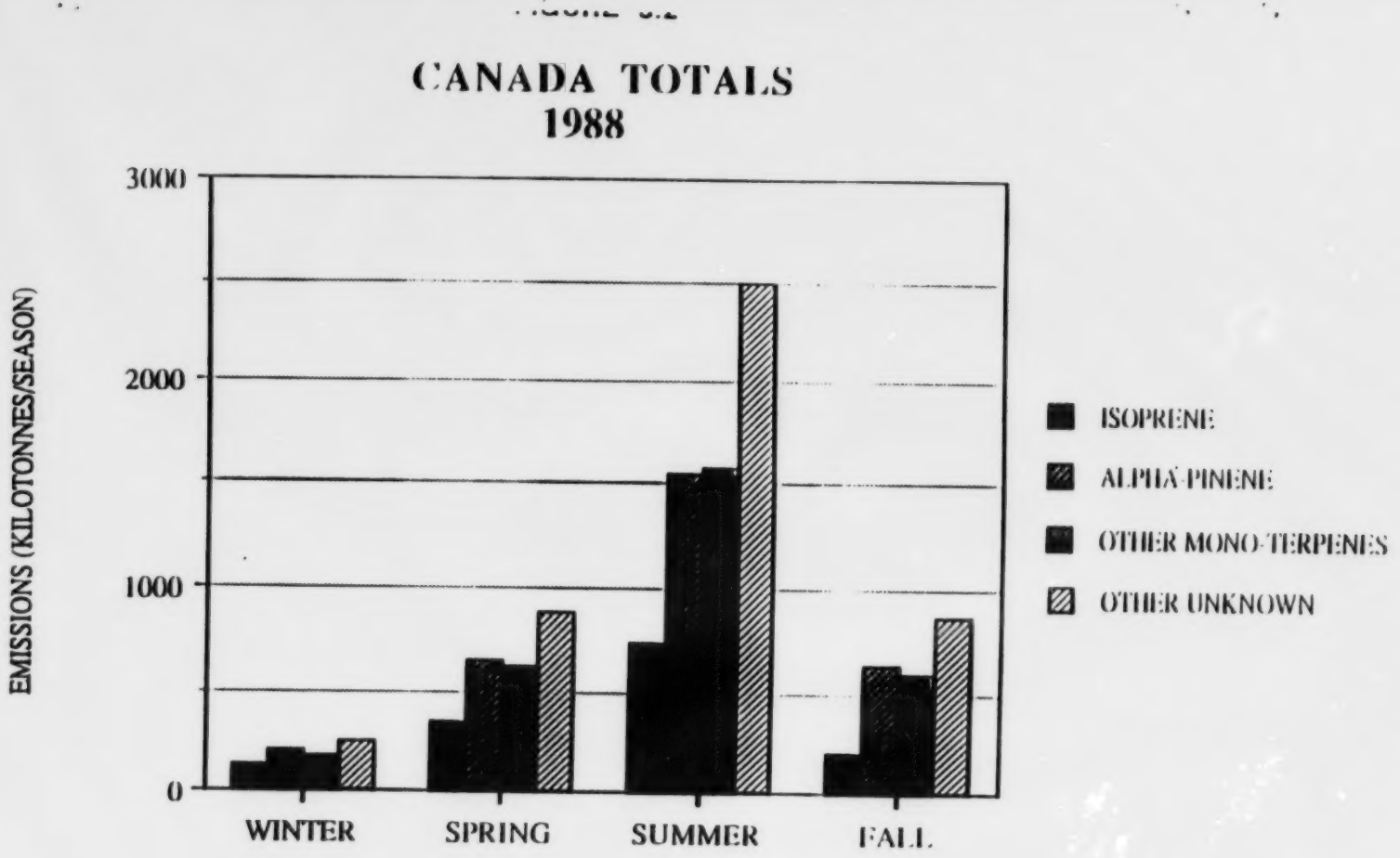
127 KM GRID

158 79 0 158 316 miles

200 0 400 kilometres

CANADA TOTALS
1985




CANADA TOTALS
1988
EMISSIONS (KILOTONNES/SEASON)
3000
2000
1000
0
WINTER
SPRING
SUMMER
FALL
ISOPRENE
ALPHA-PINENE
OTHER MONO-TERPENES
OTHER UNKNOWN

PROVINCIAL VOC TOTALS
1985

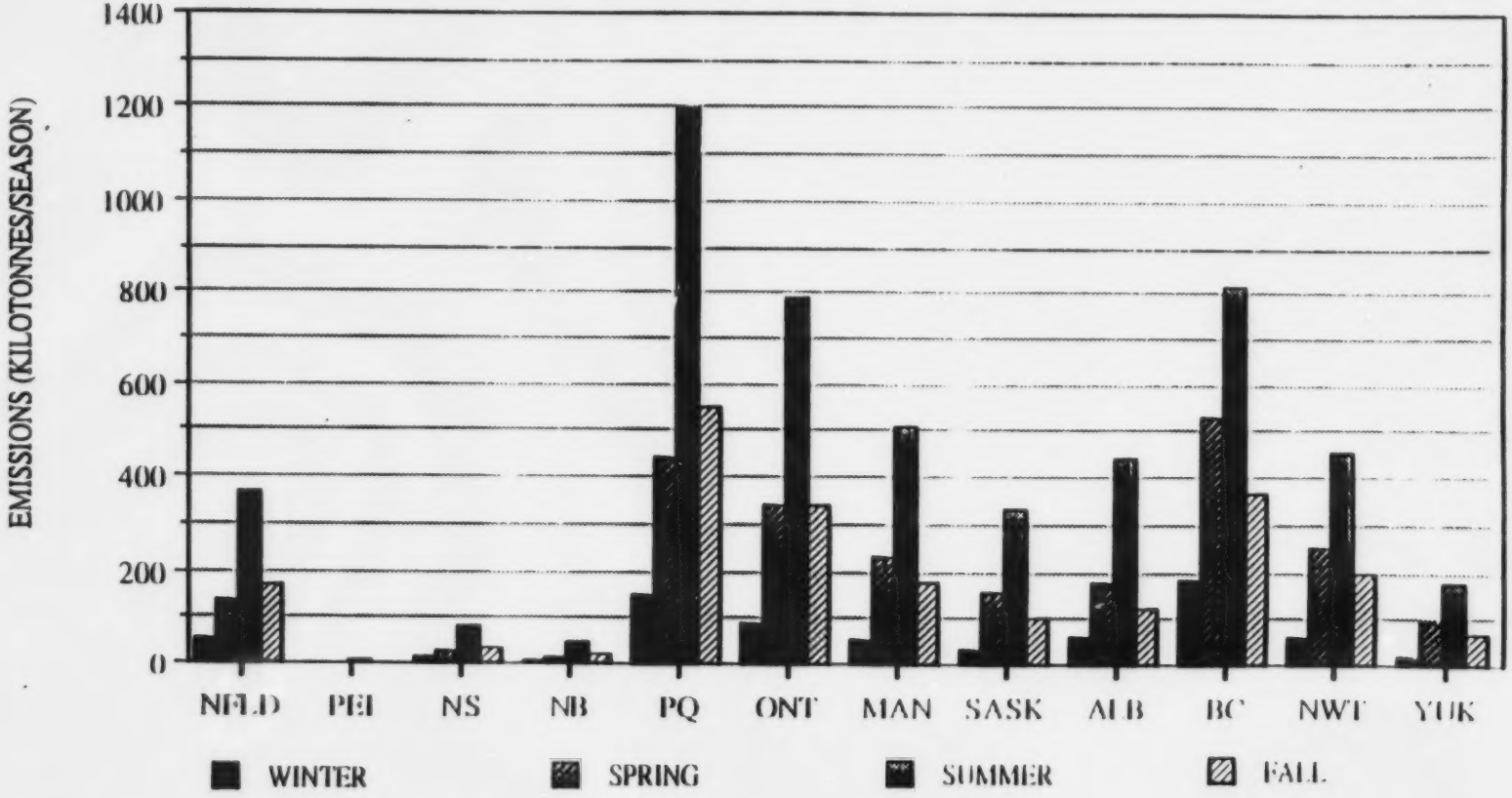
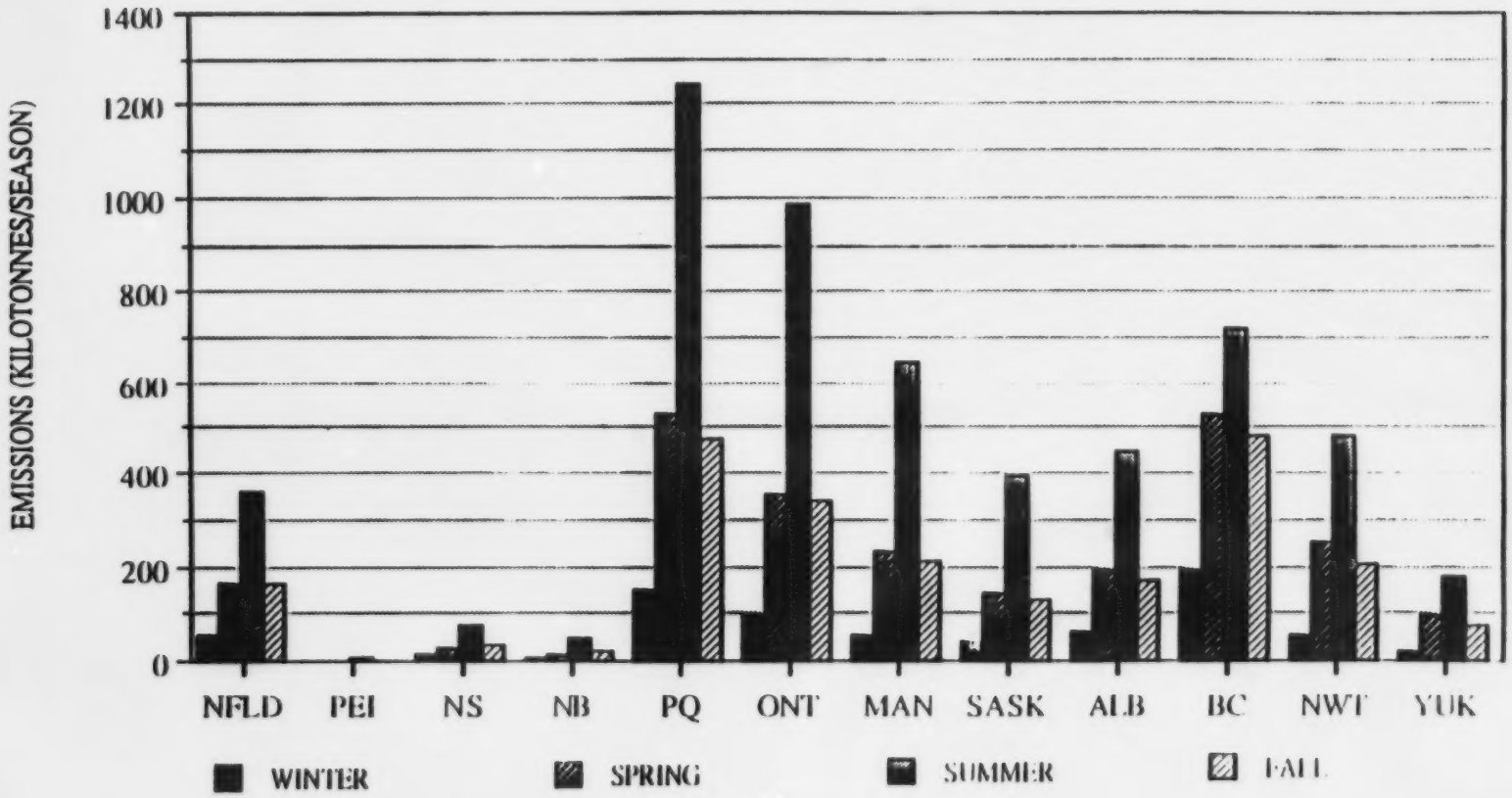


FIGURE 3.4

PROVINCIAL VOC TOTALS
1988



PROVINCIAL TOTALS
1985

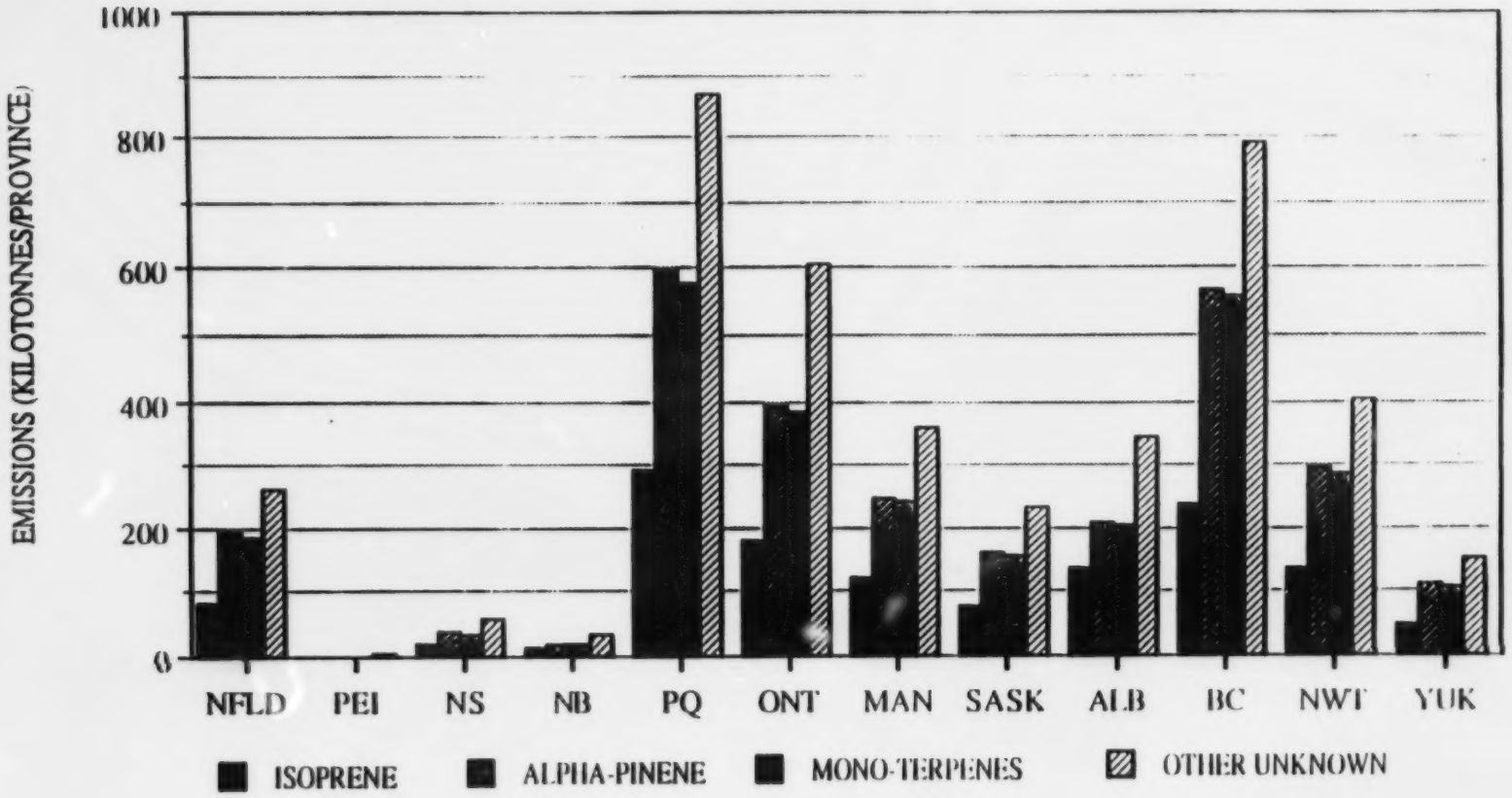


FIGURE 3.6

PROVINCIAL TOTALS
1988

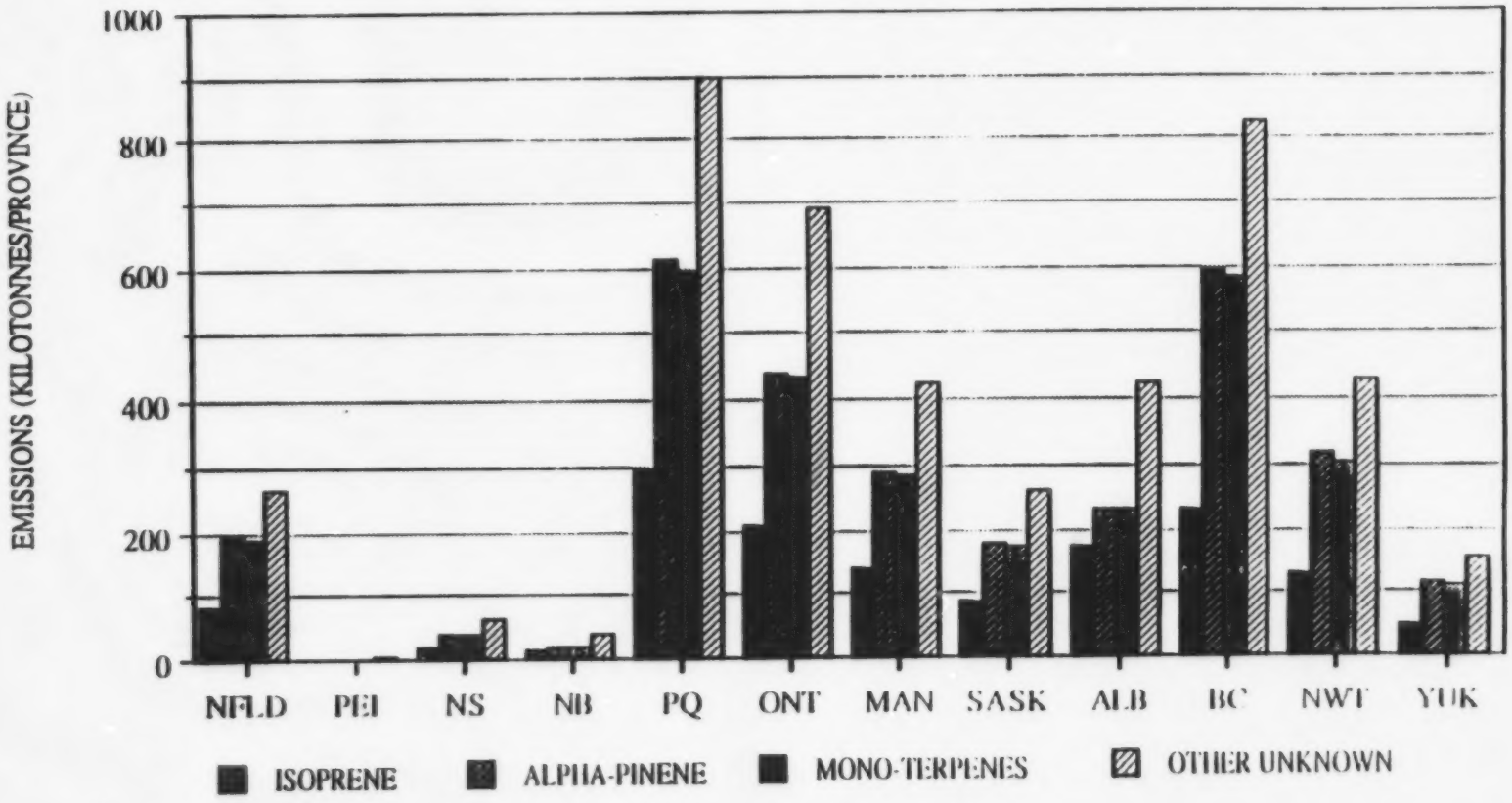


FIGURE 3.7

Emissions by Climate Zone for 1985

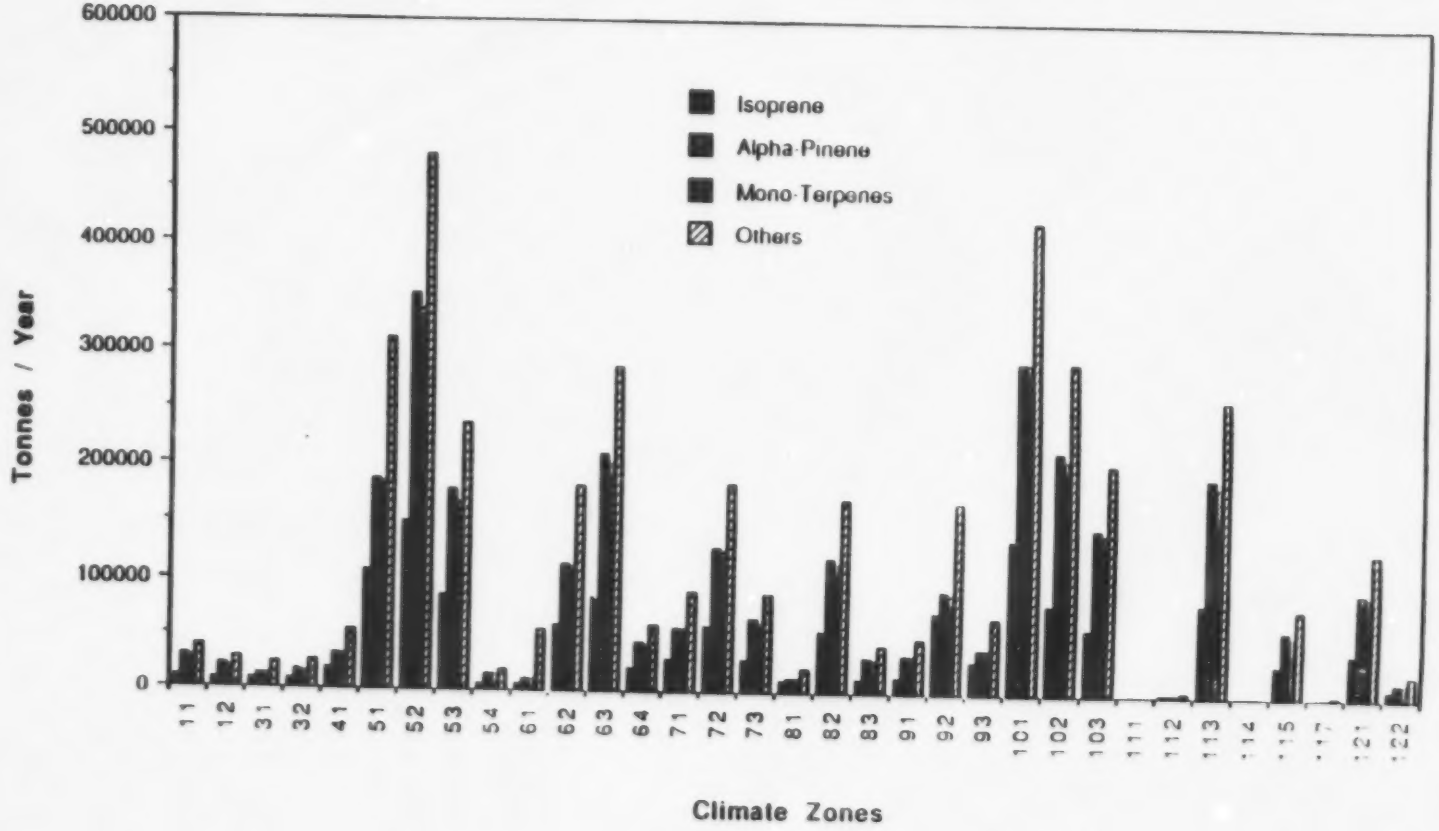
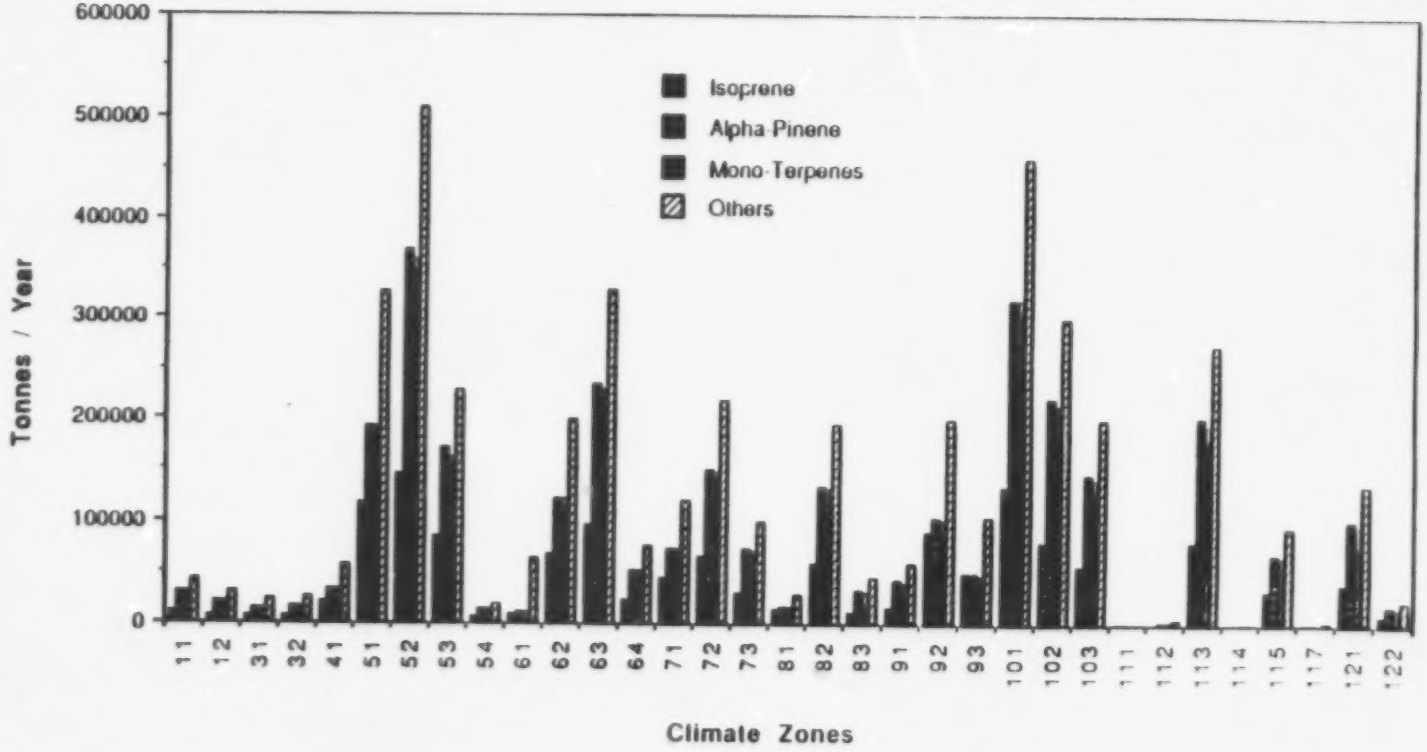


FIGURE 3.8

Emissions by Climate Zone for 1988



APPENDIX

Overview of the Canopy Model Used for Computing Biogenic VOC Emissions (Galluppi, private communication, 1989)

Overview of the Canopy Model Used for Computing Biogenic VOC Emissions (Galluppi, private communication, 1989)

The calculation of biogenic hydrocarbon emissions requires four components:

- an estimate of the biomass density in each grid cell
- frost dates for adjustment of biomass according to season
- emissions factor by vegetation class for each hydrocarbon class
- empirical adjustment factors based on temperature and solar intensity

Biomass Density by Vegetation Class:

Table A-1 lists typical vegetation species included in the biomass classification scheme. For canopy cover, Table A-2 gives the assumed contributions of high, low and non-isoprene emitting vegetation types. For non-canopy cover, emission factors are based on land area and biomass density is not explicitly used. The multi-layered canopy model distributes the biomass density from Table A-2 into eight layers. Temperature corrections are then applied to each layer, based on the leaf temperature determined by energy balance. Finally, between the first and last frost dates, the deciduous biomass contribution is set to zero. Tables A-1 and A-2 have been extracted from Galluppi (1989).

Emission Factors:

Tables A-3 and A-4 (extracted from Galluppi, 1989) give the canopy and non-canopy emission factors for a standard temperature of 30°C for the various biomass classes and vegetation components. The standard temperature emission factors are corrected for solar intensity and leaf temperature in each of the canopy layers using Tingey (1981).

For isoprene the correction factor is given by:

$$\log_{10}(E/E_{30}) = a/(1 + \exp(-b(T-c))) + d$$

where T is temperature and a, b, c and d are functions of solar intensity and temperature as tabulated by Tingey.

For non-isoprene emissions, the correction factor is of the form:

$$\ln(E/E_{30}) = -a + bT$$

where a and b have tabulated values for alpha-pinene, other monoterpenes and other hydrocarbons.

TABLE A-1

Vegetation Classes in the Biogenic Emissions Inventory System

Vegetation Class	Examples
Canopy (Forest)	
Natural vegetation:	
Oak	Oregon oakwoods, oak savanna, oak-hickory
Other deciduous	Elm-ash, northern hardwoods, beech-maple
Coniferous	Cypress savanna, Douglas fir, conifer bog
Non-Canopy (Non-Forest)	
Natural vegetation:	
Scrubland	Creosote bush, chaparral, coastal sagebrush
Grassland	Fescue-oatgrass, northern cordgrass, prairie
Agricultural crops	Alfalfa, barley, corn, cotton, hay, oats, peanuts, potatoes, rice, rye, sorghum, soybeans, tobacco, wheat, miscellaneous crops
Urban area	Urban grass, urban trees
Water (fresh and salt)	Inland lakes
Barren area	Tundra, ice, alpine meadows, desert

TABLE A-2

Forest Biomass Density Estimates

Forest Biomass Class	Forest Biomass Density (kg/ha) by Canopy Vegetation Class		
	Oak	Other Deciduous	Coniferous
Deciduous high isoprene	1,850	600	390
Deciduous low isoprene	600	1,850	260
Deciduous nonisoprene	600	900	260
Coniferous nonisoprene	700	1,350	5,590

Source: Lamb, B., A. Guenther, D. Gay and H. Westberg. "A National Inventory of Biogenic Hydrocarbon Emissions", Atmospheric Environment, 21 (8), p.1695-1709, 1987.

TABLE A-3

Canopy Emission Factors at 30°C

Hydrocarbon Compound	Forest Biomass Class	Canopy Emission Factor [$\mu g_{compound}$/($g_{biomass}$) · h)]
Isoprene	Deciduous high isoprene	14.69
	Deciduous low isoprene	6.60
	Deciduous nonisoprene	0.00
	Coniferous nonisoprene	0.00
α-pinene	Deciduous high isoprene	0.13
	Deciduous low isoprene	0.05
	Deciduous nonisoprene	0.07
	Coniferous nonisoprene	1.13
Other identified monoterpenes	Deciduous high isoprene	0.11
	Deciduous low isoprene	0.05
	Deciduous nonisoprene	0.07
	Coniferous nonisoprene	1.29
Other unidentified hydrocarbons	Deciduous high isoprene	3.24
	Deciduous low isoprene	1.76
	Deciduous nonisoprene	1.91
	Coniferous nonisoprene	1.38

Source: B. Lamb, Washington State University, personal communication, 1988.

TABLE A-4

Non-Canopy Emission Factors at 30°C and Estimated Percent Composition of Emissions

Non-Canopy Vegetation Class	Non-canopy Emission Factor [μgcompounds/ $m^2 \cdot h$)]	Estimated Emissions Composition (%)			
		Isoprene	α pinene	Other Mono-terpenes	Other Unidentified Hydrocarbons
Natural Vegetation:					
Grass	281.0	20	25	25	30
Scrub	189.0[a]	20	25	25	30
Agricultural Crops:					
Alfalfa	37.9	50	10	10	30
Barley	37.9[b]	20	25	25	30
Corn	3,542.0	0	10	10	80
Cotton	37.9[b]	20	25	25	30
Hay	189.0	20	25	25	30
Oats	37.9[b]	20	25	25	30
Peanuts	510.0	20	25	25	30
Potatoes	48.1	0	25	25	50
Rice	510.0	20	25	25	30
Rye	37.9[b]	20	25	25	30
Sorghum	39.4	20	25	25	30
Soybeans	22.2	100	0	0	0
Tobacco	294.0	0	10	10	80
Wheat	30.0	50	10	10	30
Misc. crops	37.9[b]	20	25	25	30
Water	145.0	0	0	0	100
Barren	0.0				

Source: B. Lamb. Washington State University, personal communication, 1988.

a Assumed to equal the hay emission factor.

b Assumed to equal the alfalfa emisson factor.

DEC 06 '89 12:06 SPI CANADA 4164495685

EPIC

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December 6, 1989

VIA FAX 1-819-953-5975

Mr. Frank Vena
Chief, Inventory Management Division
Environmental Protection Directorate
Environment Canada
OTTAWA, Ont.
K1A 0H3

Dear Frank:

Joe and I discussed your letter of December 4 (your file 4507-8) yesterday. At that time I agreed to respond also in writing.

In order to do this it might be well if I dealt with the matter by resin type.

1. POLYETHYLENE

For the purposes of our discussion there is no point in distinguishing between low density, linear low density and high density except to say that film extrusion involves primarily low density and linear low density with a minor component of high density resins.

Polyethylene is a resin used primarily in the packaging market.

The processes used to convert resin pellets into packaging materials are:

1. film extrusion
2. injection moulding (margarine tubs, lids etc.)
3. blow moulding (bottles)
4. paper coating (very much like film extrusion except that the film is applied to a paper substrate

The process which has the greatest potential to emit materials is film extrusion. In this process you have a very thin, hot material with a large surface area. I have provided you with data on the losses from a film extrusion operation.

Injection moulding involves the forcing of a molten material under high pressure into the closed cavity of a steel mould where it is cooled. It is essentially a closed system. The part is cool when the mould is opened and hence not emitting volatiles.

Blow moulding involves the rapid extrusion of a thick section (parison) which is then clamped or pinched by a mould and expanded in the mould where cooling occurs. The thickness and relatively

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

low surface area of the parison exposed in air for a very short time would also be classed as a low emitter.

In your calculations of emissions I would suggest you use the figures which I gave you for the 185 kt of film resin and something less for the balance of the polyethylene consumed (362 + 141 - 185) kt.

In your consideration of the difference in emission factors between my numbers and the 1978 Monsanto factors you need to consider the changes in resin production technology during the last 10 to 12 years. There is very little low density resin now being made by the high pressure process. Gas phase production of linear low density has displaced it. This process polymerizes ethylene as a gas at low pressure to produce a dry powder. There are other processes to produce LLDPE however these are similar to the DuPont process and the volatiles would be similar to those measured by DuPont for 30 years. The technology to make high density polyethylene has also changed and slurry processes are no longer as important as they were in the 1970's.

2. POLYPROPYLENE

Polypropylene is a polyolefine as is polyethylene. The two materials compete in many markets and the systems to process them are identical. Polypropylene may be used to make glossy transparent films and as such finds application as the wrapping for cigarettes and baking products. It is of course also injection moulded. It is not blow moulded as a rule.

The process to manufacture the resin is akin to that used to make linear polyethylene.

There have been major improvements in the manufacture of polypropylene over the last 10 years. New catalysts have virtually eliminated the production of atactic polypropylene. Old processes required solvent extraction of atatic (amorphous) polypropylene from the desirable isotactic fraction. These extraction processes and their residues as well as some residue of atactic material could account for the high emission factors given by Monsanto Research.

I suggest that you apply my polyethylene factors to the 50% of polypropylene which goes into film and something less for the balance.

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

3. POLYSTYRENE

Polystyrene consumption of about 190 kt can be divided equally between packaging, construction and serviceware (cups, trays etc.)

Of the 55 kt in construction, 27 kt is blown with hydrocarbons and the emission factor I provided of 50 g/kg should be applied. The other 28 kt used in construction is extruded foam of a closed cell nature. It has been blown with CFC's and will ultimately be blown with HCFC's and HFC's. These extruded foams contain the blowing gas in their closed cell structure. It is this containment of blowing agent which provides their better thermal properties.

Polystyrene used in packaging is largely processed by thermoforming, vacuum forming, or injection moulding to produce yoghurt tubs, cookie separators and materials like that. The foam packaging and cups component is included in my 27kt which I have put into the construction category.

In your inventory calculations you cannot apply the Monsanto factor to those of the end uses which are not foam related. The Monsanto factor is a weighted number which includes the high emissions of hydrocarbons from foam.

I believe that a detailed investigation of the packaging and serviceware markets would show very low emissions for products which are injection moulded, thermoformed etc. Serviceware which is not included in my 27 kt of foam but is of a foam nature (hamburger clam shells etc.) uses HCFC-22 as a blowing agent.

4. POLYESTER (Styrenic, unsaturated)

These materials are thermoset polyesters. I have provided you with figures for the 12.2 t used in laminations (fibre reinforced plastics). These are used primarily in spray lay-up applications and have high emissions.

Other applications may use impregnated batts, viscous filled systems etc. which will have lower emissions. The Monsanto number might well be appropriate.

5. ACRYLONITRILE BUTADIENE STYRENE (ABS)

This resin is used in telephones, machine housings, drain pipe.

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

Pipe is manufactured by an extrusion technique. Thick sections are forced from an extruder into a forming box where the material is held to a shape and cooled. The thick section and low surface area would provide for low emissions in my opinion. Telephones, instrument housings etc. are injection moulded ie. high pressure into a closed cavity.

The Monsanto report does not list the applications considered by them and hence I cannot comment on their numbers except to say that 5% material losses do not occur in the processes which I am familiar with.

6. ENGINEERING RESINS

6.1 Acetal

These resin are used as gears etc. in appliances and machines. The Monsanto data is outdated. Acetals can emit some formaldehyde, one of the principal chemicals used in their manufacture. Over the last 5 to 6 years manufacturers of acetals principally E.I. duPont and Celanese Corporation have modified their resin production facilities to provide assurance to users that formaldehyde emissions during processing will be substantially less than 1%.

6.2 Acrylics

Because 50% of the acrylics used go into cast sheet and coatings we agreed to use the Monsanto number. In reality their factor should only apply to about 50% of the consumption and a lower factor would apply to the 50% used in extrusion and moulding.

6.3 Epoxy

Epoxies are used primarily as coatings and should belong with paints. Check for double accounting with paints). A small quantity is used to produce specialised laminates. (Probably less than 10% - 20% of Canadian consumption).

6.4 Phenol Formaldehyde

Probably 50% of this category is used in adhesives. The plywood industry might use half of the adhesives. You should speak to adhesive manufacturers about the nature of their materials. Solvents etc. might be used to carry some components.

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

I would estimate about 33% of these resins are used as moulding powders to produce thermoset products such as "Bakelite" used in electrical switches etc. The Monsanto Emission Factors are weighted factors and contain the adhesives.

There is a fledgling insulation industry in Canada making phenolic foam. Those plants are just starting and use CFC's as blowing agents.

6.5 Polyamide (Nylon)

Most polyamides produced in Canada are used in the production of nylon fibre.

DuPont Canada is the principal manufacturer and employs largely, continuous polymerization spinning technology.

The Monsanto report does not include a consideration of the production of nylon fibre with the exception of some bristle production.

Having worked in the nylon filament production business for many years I know that the losses are very much less than the 3.4% in the Monsanto report. The Monsanto factor should not be applied to the 83% of Canadian consumption which goes into fibre. Losses of less than 0.5% might be more appropriate.

6.6 Polycarbonate

A small item and I have no comment.

6.7 Thermoplastic Polyesters

The principal applications are textile fibre followed by PET bottles (18 kt). I'm sure the Monsanto factor is too high for Canada since it includes many applications which are not of note here. Canada has no manufacturer of polyester resin other than Celanese which uses it in their continuous fibre operation. Resin to make bottles is imported as resin or as semifinished materials called preforms. Emissions from Canadian polyester processing should be very low.

6.8 Polyphenylene

No comment.

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

6.9 Polyurethane

This section should be subdivided into Flexible Foam, Rigid Foam and Thermoplastic polyurethanes.

The rigid foam market represents 30% of the total. CFC's and water are used as blowing agents. The other components are polyols and isocyanates. The isocyanates are volatile but react immediately with air and moisture to become solids.

Flexible Foam is manufactured using CFC's, methylene chloride and some water as blowing agents. You should contact Craig Barkhouse of Reeves Bros. for more information. (416-259-3363)

Thermoplastic polyurethane is less than 2% of consumption.

The high emission factors in the Monsanto report can be attributed to the flexible foams. The rigid foams should be given a very low emission factor since you are not considering CFC's and CO_2 in your inventory.

6.10 Urea Formaldehyde

Probably 70-75% of these products are used as adhesives with maybe 10% used as moulding compounds. The remainder probably find application as coatings. I am unable to help you with information on coatings and adhesives.

7. POLYVINYLCHLORIDE

The primary processing techniques used in Canada would be extrusion and injection moulding.

Building and construction account for 210 of the 327 kt of resin consumed. Principal applications would be things such as vinyl siding, window frames, pipe etc. The figures which I have given for emissions would apply to all of these applications as well as other extrusion operations such as those in the production of packaging film, transportation applications and wire coating.

Some injection moulded applications would be less.

If you wish to be conservative the use of an emission factor of 5g/kg for the total product mix would provide that assurance.

Mr. Frank Vena
Environmental Protection Directorate
Environment Canada
Ottawa, Ontario
December 6, 1989

From the information available I an unable to comment on the Monsanto factor except to say that if the point source was a plant using plastisols for a dip coating operation then solvent emission could be very high.

If I can be of further assistance, please call.

Sincerely,

F. H. Edgecombe

F. H. Edgecombe, Ph.D.
Executive Director

FHE/ns

HAROLD W.QUINN
Consultant, Environmental Affairs

610 River Ridge Drive
Box 45, R.R.# 1
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Phone (613) 544-1227
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December 12, 1989

Mr. Frank Vana
Industrial Programs Branch
Conservation & Protection
Environment Canada
Place Vincent Massey
351 St. Joseph Blvd.
Hull, Quebec
K1A 0H3

Dear Frank:

As requested by you yesterday, I have assembled process emission data (continuous and intermittent) presently available as part of the VOC emissions survey of the petrochemical industry in Canada. Although most of these data have already been submitted in writing to Levelton & Associates, I have obtained a few by telephone. These data are shown in the attached table along with the estimated emissions for the same production units reported by Levelton & Associates in their report "VOC Emissions Inventory for the Organic Chemical Industry in Canada" submitted to Environment in September, 1988.

The Levelton inventory represented an estimate of all non-methane VOC emissions, although it identified 92.8% of the total with process emissions. The striking difference between the industry reported process emissions and the Levelton data appears to be the result of the fact that the largest VOC-containing vents are sent to a flare or furnace which destroys essentially all of the organic molecules. It was acknowledged by Levelton that their numbers do not reflect that step in the process. Although I do not have data for total flow to flare or furnace in all cases, there are sufficient in this table to reflect the impact of that control technology on the net VOC emissions. Where I have shown zero control efficiency, it is assumed that the emission goes directly to the atmosphere.

We do not yet know what the other most significant contributor, fugitive emissions, will represent in total for these same production units. However, even if they are as large as the net process emissions, the total will still be very much smaller that suggested by the Levelton report.

I recognize that we are all anxious to complete the survey currently underway in order to get a more accurate emissions database than we have had to date. However, I trust that the summary which I have provided will assist your interim assessment of the situation when preparing your report for the NOx/VOC Management Plan. If you have any questions, please give me a call.

Yours sincerely,

Harold W. Quinn
Consultant to CCPA

Copies to: Wayne Edwards - Lavalton
Doug Bisset - Shell
Bill Neff - CCPA

HAROLD W.QUINN
Consultant, Environmental Affairs

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Box 45, R.R.# 1
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PETROCHEMICAL INDUSTRY VOC SURVEY

PROCESS EMISSION DATA (tonnes in 1988)

Production Unit	No.of Units	Total VOC Flow	Control Efficiency	Total Emissions	Levelton Data(1985)
P.E.-LD	2	220	0	220	
		1334	99.5	7	
Total		1554		227	9000
P.E.-LLD	3	115	0	115	
		2745	98	55	
		5160	99.5	26	
		?	?	11	
Total		8020+		207	7411
P.E.-HD	2	199	0	199	
		4193	99.5	21	
Total		4392		220	2568
Ethylene	4	1242(c)		1242(c)	
		774	0	774	
		8556	99.5	43	
		10415	99	104	
		7678	98	154	
		66	90	7	
		817	80	163	
Total		29588		2487	11509
E.O./E.G.	3	?	?	712	6628
Styrene	1	1300	99	13	
		?	99.6	78	
		?	99.8	33	
Total		?		124	4967
Totals				3977	42083

(c): calculation using emission factors

HWQ
12/12/89

MOTOR VEHICLE MANUFACTURERS' ASSOCIATION

15 Adelaide St East
Suite 1602
Toronto, Ontario
Canada M5C 1Y7
Tel (416) 364-9333

December 1, 1989

MVMA #: 54032BHJ.L01

Mr. Arthur Sheffield
Regulatory and Economic Affairs Division
Environment Canada
15th floor
351 St. Joseph Blvd.
Hull, Quebec
K1A 0H3

Dear Mr. Sheffield:

Further to recent discussion concerning NEB fuel demand forecast data, the MVMA submits the enclosed information respecting the industry's new vehicle sales projections.

We hope that you will find this data helpful. Unfortunately, it is not as complete as that which was requested in our earlier meeting with you and Mr. Waghmare of the NEB. The MVMA continues to pursue more complete information which, when received, will be forwarded to you. In the meantime, we acknowledge the fact that you must proceed with the development of emission forecasts as part of the NOx/VOC management plan and other emissions-related activities.

Please accept our apology for the delay in this response. Should you require additional information, please contact me directly.

Yours sincerely,

Mark A. Nantais
Executive Director, Committees

MAN:

Enclosure

Members:
Chrysler Canada Ltd.
Ford Motor Company of Canada, Limited
General Motors of Canada Limited
Mack Canada Inc.
Navistar International Corporation Canada
Paccar of Canada Ltd.
Volvo Canada Ltd.
Western Star Trucks Inc.

November 29, 1989

MVMA #: 54032AHJ.K20

To: File

Subject: NEB vs Industry New Vehicle Sales Forecast

A) NEW PASSENGER CAR SALES

1) High Oil Price/High Economic Growth Scenario.

Actual Passenger Car Sales:

1986	1,091,117
1987	1,064,865
1988	1,056,310

Source: Statistics Canada

MVMA Industry Forecast (millions of units)

1988	.980
1990	.977
1995	1.102
2000	1.159
2005	1.224

NB: See Attached Graph

2) Low Oil Price/ Low Economic Growth Scenario

1990	.950
1995	1.034
2000	1.089
2005	1.137

B) NEW TRUCK SALES

1) High oil price/High economic growth scenario

MVMA Industry Forecast (millions of units)

1990	.491
1995	.565
2000	.614
2005	.682

2) Low Oil Price/ Low Economic Growth

1990	.472
1995	.532
2000	.565
2005	.595

3) General Trend Data; Class 6,7 & 8 Trucks Only

1990	.024
1995	.027
2000	.030
2005	.034

MAN:

EXECUTIVE SUMMARY

I INTRODUCTION

Volatile organic compounds (VOCs) are precursors of photochemical oxidants, producing ozone by reactions with NO_x compounds in the atmosphere. Elevated ozone concentrations are recognized as a serious air pollution problem. Many studies have examined the control of VOC emissions from stationary point sources with add-on controls. However, little work has been directed towards achieving and managing VOC emissions through the use of product substitution and process change strategies.

The purpose of the study is to review potential VOC emission control measures associated with the use of solvents in small industrial and commercial settings. Specific tasks included:

- identify the areas or sectors where add-on control, product substitution or process changes may be feasible;
- improve the inventory of VOC emissions from solvent loss;
- describe and evaluate the potential for VOC emission reductions through add-on control, product substitution or process changes;
- suggest actions the government might consider to facilitate VOC control measures.

II IDENTIFICATION OF TARGET AREAS/SECTORS

VOCs, by definition, have vapour pressures greater than 0.1 mm Hg at 25°C and boiling points less than 240°C (US EPA). They include but are not limited to, a variety of compounds such as hydrocarbons, aromatics, ketones, alcohols, esters and ethers.

The commercial and end-use products/processes which emit VOCs are highly varied. They are classified as follows:

- paint application
- application of glues and adhesives
- printing industry
- metal degreasing

- dry cleaning
- consumer products
- pest control products
- general purpose solvent use
- miscellaneous industries

III EVALUATION OF OPTIONS FOR PRODUCT SUBSTITUTION, PROCESS CHANGES OR ADD-ON CONTROLS

In general, product substitution strategies can be directed at two major areas; minimizing the use of pollutant-emitting solvents and substituting non-polluting or less-polluting solvents. Process change alternatives include altering the production or application process.

Add-on control devices are generally restricted to large scale operations where centralized units are more cost-effective to install. VOC reductions from solvent using operations can be of two major types; processes which recover solvents and processes which destroy VOC emissions. The major types of add-on control devices involve the following processes.

- Condensation or
- Absorption (Scrubbing) or
- Adsorption or
- Incineration: Non-catalytic or catalytic

Paint Application

VOC emissions from paint applications were estimated at 188 kt. Most of the emissions are of moderate to very reactive compounds.

Product substitution options such as powdered coatings, low solvent paints and water-borne formulations offer excellent potential to reduce VOC emissions. VOC reductions by product substitutions could reach 35 kt. Add-on controls applied to 25% of the industrial sector could reduce emissions by 25 kt.

Application of Glues and Adhesives

The application of glues and adhesives were estimated to emit about 35 kt of VOCs. Since the solvent contents vary between 5 and 80% by weight, it is conceivable that product substitutions to low solvent content glues and adhesives could reduce VOC emissions by 25% or almost 9kt.

Printing Inks

The printing industry, because of the high cost of rotogravure inks and because of aesthetic problems with Web heat set inks, already employs add-on controls which effectively reduce VOC emissions. The remaining VOC emissions were estimated at 20 kt. Add-on control devices have the potential to reduce VOC emissions a further 4.6 kt if applied to 50% of the flexography processes. If the control level were increased to 90% of all printing operations, VOC emissions might be reduced by about 14kt.

Metal Degreasing

Many of the solvents used in this industry have very low reactivities. Consequently, the emissions of reactive compounds is only about 17 kt compared to a total VOC emissions of 34 kt. Add-on controls, applied industry wide, could reduce reactive VOC emissions by 3.4 kt. Process changes and good house keeping practices could reduce the reactive VOC emissions by about 5 kt.

Drycleaning

Synthetic solvents account for about 75% of the dry cleaning fluids used at present. They are expected to account for an increasing proportion of the drycleaning fluids because of the fire hazards associated with petroleum solvents. Perchloroethylene, a relatively non-reactive solvent, is the primary synthetic solvent in use. Total VOC emissions are about 14 kt with almost 11 kt being attributed to synthetic solvents. The high cost of synthetic solvents has already lead to the use of closed systems with solvent recovery achieved by built-in or add-on controls. Incineration could reduce VOC emissions by almost 3 kt from petroleum dry cleaning applications. Controls on vents and improved handling practices to reduce exposure of solvents to air could reduce emissions by 1.5 kt.

Consumer Products

VOC emissions from consumer products were estimated at 82 kt. This is broken down into automotive products, 37 kt; household products, 12 kt; and personal care products, 22 kt. Aerosols are used in all of these

sub-sectors. The total quantity of aerosols used in all these sub-sectors. were estimated at 11 kt. Combined product substitution options could reduce VOC emissions from consumer products by 26 kt.

Pest Control Products

VOC emissions were estimated at 11 kt. Long term reductions of 30% or about 3 kt may be possible through a variety of product substitution and application change options.

Miscellaneous Industries

These miscellaneous industries accounted for VOC emissions of 150 kt. The reactive fraction amounts to 135 kt.

IV POSSIBLE GOVERNMENT ACTIONS TO FACILITATE PRODUCT SUBSTITUTION, PROCESS CHANGES OR ADD-ON CONTROLS

The inventory of VOC emissions indicates that the greatest potential for VOC reductions would come from the paints and coatings sector. Considerable reductions may also come from the consumer products sector. Priority should be given to complete inventories for general solvent use and to resolve the inventories for glues and adhesives and consumer products.

The government can act to facilitate VOC emission reductions in five ways:

1. Public awareness to alternative products through labelling;
2. Setting of VOC emission objectives and standards for measurements;
3. Regulations to ban reactive VOCs or force reformulations and add-on controls;
4. Incentives to encourage consumers to buy lower emitting products and to encourage industry to develope new formulations;
5. Fundamental research and development into best available technologies, VOC control systems, etc.

TABLE 5 SUMMARY OF MAJOR OPTIONS FOR VOC REDUCTION

Product	Possible VOC Reduction Strategy	Estimated Annual Emission (t)	Possible Annual Reduction (t)
1. Paint Application	- 50% ext. oil base paints reduced to 0.25 kg/L emission limit	188,000	2,030 (trade)[1] 4,960 (all)[2]
	- 50% primers reduced to 0.25 kg/L emission limit		3,210 (trade) 7,830 (all)
	- substitution of water-base for 75% of interior oil-base		5,350 (trade) 13,050 (all)
	- substitution of 0.2 kg/L solvents for 25% of thinners		4,070 (trade) 9,940 (all)
	- Add-On controls (25% use level)		24,700 (all)
2. Application of Glues and Adhesives	- use of water base and/or low solvent adhesives	35,000	8,750
3. Printing Inks	- 90% of industry with add-on controls - combined reduction efficiency of 75 - 90%	20,010	13,700
	- 50% of flexography process with reduction efficiencies of 90%		4,600
4. Industrial/Commercial degreasing	- add-on controls to reduce VOC emissions process changes	17,000	5,100 3,400

Product	Possible VOC Reduction Strategy	Estimated Annual Emission (t)	Possible Annual Reduction (t)
5. Dry cleaning	- add-on controls - process changes	14,000	2,000 1,500
6. Consumer Products			
a. Automobile products	- ban windshield wash 6 months/yr - 50% reduction in VOCs from propellants	37,000	13,950 220
b. Household products	- banning of reactive VOCs from propellants - 20% reduction in solvent content of products	12,000	910 4,970
c. Personal use products	- banning of reactive VOCs from propellants - 20% reduction in solvent content of products	22,000	1,400 4,710
d. Aerosols		11,000	
7. Pest control products	-reduction of solvent content -improved transfer efficiency -product substitution	11,000	
8. General solvent use	-lower vapour pressure solvents -solvent recycling	Not available	
9. Miscellaneous Industries		135,000	
		502,000	

Notes:
1 Including trade sales only
2 Including industrial and trade sales

RAC The Railway Association of Canada

November 23rd, 1989

Mr. Frank Vena
Chair, Inventories Sub-Group
NOx-VOC Consultation
Chief, Inventory Management Division
Conservation and Protection
Environment Canada
Ottawa, Ontario
K1A 0H3

Dear Sir,

This has reference to the on-going CCME NOx-VOC Consultation process and specifically to the requirement to produce National Emissions Inventories and Projections. The Railway Association of Canada (RAC) is pleased to provide historical data and calculated projections of Railway Traffic, Fuel and Locomotive Emissions for the period 1975 to 2005. This letter is a follow-up to data previously sent by FAX to Mr. Arthur Sheffield who is currently assembling such data on behalf of CCME. This letter will include observations, conclusions and background notes relative to the inventories and projections of both RAC and CCME.

In being required by CCME to calculate emissions inventories for 1985 to 2005, Environment Canada was set an immense and demanding task. The scope of categorizing the economic, operational and emissions activity of every sector of Canadian private, public and industrial life is challenging enough for a current year, let alone for 15 years in the future. In this respect, RAC is pleased to be able to offer assistance with the railway sector of Canadian emissions. RAC believes that an examination of the emissions from railway operations requires the specialized expertise available within the industry.

.../2

A/Misc8/WGB21/fj

... Ste. Catherine Street West, Suite 721, Montreal Que. H3B 1H9 • (514) 849-4274

To this end, a detailed study has been made of the past and anticipated future operations of the two principal railways in Canada, CNR and CP Rail. The results of this review for CNR has already been disseminated for your review and consideration. A similar pattern for CP Rail and the industry as a whole has been confirmed. Detailed notes on the derivation of data have been appended to this letter as Appendix III. The spreadsheet calculations are included as Appendix I with graphical results plotted in Appendix II. Please note that the railway traffic data is presented in English measure rather than metric. This is to maintain continuity with historical data and with current North American railway practice. Emissions are quoted in metric units for conformity with CCME documentation.

Observations

1) The CCME Railway emissions inventories for 1985 and projections for 1990-2005 are understood to be derived from Statistics Canada and National Energy Board data. This data was documented in the CCME report "Development of a National Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOC) Management Plan for Canada" Technical Annex - Section 2.2 of July 1989. The data was presented as a "high growth" scenario, with no operational improvements factored in to the projections.

2) RAC has been able to refine existing data to reflect reasonable projections which do include on-going operational improvements. As noted in Appendix III, these improvements conservatively project continued reductions in fuel consumption per gross ton-mile of traffic, as well as a continuation of improved net ton-miles per gross ton-mile run. (See Graphs 2 and 3, Appendix II)

3) These operational improvements have been achieved through large capital and operating fund investments in rolling stock, physical plant and operational techniques. There is a clear opportunity for such improvements to continue when associated with an effective return on investment. (See RAC presentation to Transport Canada Hearings, September 1989).

4) The improvements noted above have been factored against traffic volume expectations. These projected traffic volume increases are primarily based upon the long term (1975-1989) growth rate, tempered by depressed traffic experienced in 1989 and expected for 1990. (See Graph 1, Appendix II)

5) The combination of traffic growth over the period 1975-2005 and reduced fuel consumption per ton-mile over the same period, leads to reasonably stable fuel consumption. (See Graph 4, Appendix II)

.../3

6) Stable fuel consumption implies stable emissions output from locomotives, given uniform emission factors. (See Graph 5, Appendix II)

7) RAC has performed an in-depth review of locomotive emissions test data to arrive at a set of Emission Factors based on testing of a large and representative sample of locomotives. (See Appendix III, Section 7)

8) While reviewing the results of the RAC emissions inventories, an opportunity was taken to compare with other sources. This review included the AAR analysis of the "Radian/EPA" report. Data from this Modal comparison was previously used by RAC in September 1989 at the Transport Canada Hearings on Emissions. The NOx and HC (VOC) figures from both sources showed a good match per kiloton-mile. It was noted while conducting this review that the Graph titled "Modal Emissions Summary" prepared for RAC in September 1989 requires a labelling correction on the Y-axis. The kilograms of Emissions should, of course, be per Revenue KILOTon-mile as was calculated for the graph and normally used in our industry. The Modal comparison, the graphic image and the fact that railways are more efficient remains unchanged. Users and readers of the RAC presentation for Transport Canada should replace the original graph with the revised version included as Graph 7, Appendix II for your convenience.

9) The RAC calculation of emissions such as NOx and HC using anticipated operational data, differs greatly by year 2005 from the CCME "No Improvement" scenario. For instance, CCME predicted NOx in 2005 is well over 50% higher than RAC calculations. (See Graph 5, Appendix II)

10) Anticipated locomotive replacements in the late 1990's can have a small but measurable and beneficial effect upon fuel efficiency and emissions inventories for the year 2005. A conservative (i.e. small effect) scenario in this regard is included in RAC's submission. (See Appendix III, Section 8)

11) The current published CCME breakdown of emissions inventories by Provincial jurisdiction are understood to be derived from NEB data. The RAC is currently reviewing this data as we have previously noted provincial allocation discrepancies between Statistics Canada fuel data (at one time based on deliveries) and Railway data used for payment of provincial fuel taxes (based upon usage and traffic). (See Appendix III, Section 5)

.../4

12) More germaine to the NOx-VOC investigations than overall provincial fuel and emissions distribution, is intra-provincial distribution by Urban and Rural categories. To this end as per a recent Environment Canada request, RAC will investigate whether internal Railway statistical data on traffic by subdivision would provide a viable Urban/Rural breakdown. At this time, we are confident that this or other similar approach will confirm and quantify, the self-evident nature of Canadian Railway operations being heavily weighted towards rural and remote areas.

13) Railway Passenger Service has been a small, and will apparently become a smaller, contributor to emissions inventories in Canada. Annual data on traffic and fuel consumed in Passenger Service as published by Statistics Canada apparently has difficulty in some years in separating VIA Rail data from those of the railways over which VIA runs. A preliminary assessment of Passenger Service emission is included as a spreadsheet in Appendix IB. Several fuel figures from the mid 1980's remain to be cross-checked. However, in the aggregate, Railway Passenger Service (Mainline, Commuter, Regional) emissions should not exceed 5% of those in Freight Service in year 2005. While more precise figures would be an ideal target, the magnitude does not seem to require immediate additional work for the purpose of the National Inventories Totals. It might be expected that route specific, and traffic volume specific comparisons may be required for other phases of the NOx-VOC consultation process. Specialized expertise resident in VIA and commuter train Authorities may be necessary at that time.

14) A cautionary note should be added to the global emissions statistics provided for both Freight and Passenger services. While an excellent Modal comparison is facilitated on an industry wide basis, any attempt to use the overall average of, say, NOx in kilograms per 1000 Net-Ton-Miles, against a particular revenue move, will almost certainly overestimate the emissions produced. Specific Revenue traffic moves require specific fuel consumption analysis against which emission factors can be applied. RAC members are best positioned to make these evaluations as may be necessary in future phases of the NOx-VOC consultation process.

15) The contacts of RAC and RAC members with the Railway industry in the United States will give significant benefit in refining locomotive emissions information. Current work undertaken with relation to the State of California emissions investigation is expected to expand available data on railway emission factors as well as clarify future trends in engine development. RAC fully expects to make use of the expertise of professionals in the field of Railway locomotive emissions to assist the CCME in having clear and realistic data with which to make decisions.

.../5

Conclusions

1) Straightforward, logical and statistically based projections by RAC of future Canadian railway operations show that total emissions from locomotives will not grow over the next 15 years. This achieves a large portion of the CCME targetted savings over levels of emissions predicted by CCME that did not include productivity and efficiency factors.

2) Canada's Railway industry, through well chosen investments and efforts in the past, and through similar policies in the future, will continue to achieve national emissions goals of controlling emissions at or below 1985-1987 levels. This can be accomplished without regulatory action while still sustaining growth in traffic handled.

3) The inherent efficiency of Railway operations on separate and privately financed rights-of-way can benefit emission objectives as well as alleviate other public concerns of congestion, costs and safety on publicly financed facilities.

4) Railway operations in Canada are primarily in rural and remote areas and hence cannot significantly contribute to current emissions levels in urbanized regions. A shift in traffic to the railway mode would result in a reduction in emissions from the Transport sector.

5) The large discrepancy between the CCME emissions estimates and the RAC projections warrant a reevaluation of proposed regulations and emissions reduction objectives.

In closing, the Railway Association of Canada welcomes the opportunity to share our operational experience with others in the CCME NOx-VOC Consultation process. We expect to continue to review facts and views presented and make these available for the decision making process currently at work.

Yours very truly,

R.H. Ballantyne
President
Railway Association of Canada

A/Misc8/WGB21/fj

APPENDIX 1A

SPREADSHEET DATA
FOR
RAILWAY FREIGHT FUEL, TRAFFIC, & EMISSIONS

RAILWAY ASSOCIATION
OF
CANADA

NOVEMBER 1989

CNR HQ MP&CE
WGB 12/11/89
Lotus2.01"RAC_CCME"

DATA SOURCES :-
CNR OPERATING STATISTICS Report to CTC
CPR OPERATING STATISTICS Report to CTC
STATS. CANADA Annual Report for ALL Rlwys.

RAILWAY ASSOCIATION of CANADA

FUEL CONSUMPTION DATA	DATA or CALCULATION SOURCE			YEAR 1975	YEAR 1976	YEAR 1977
MAINLINE & BRANCHLINE FREIGHT SERVICE	STATS.CAN.	- I.G.	STD.	407,052,164	419,203,247	436,291,345
			NEW			
			ALL	407,052,164	419,203,247	436,291,345
YARD SWITCHING SERVICE	STATS.CAN.	- I.G.	ALL	33,676,252	36,409,975	36,784,996
WORK TRAIN SERVICE	STATS.CAN.	- I.G.	ALL	8,311,573	8,975,287	10,010,070
TOTAL FUEL - ALL FREIGHT OPERATIONS	STATS.CAN.	- I.G.	ALL	449,039,989	464,588,509	483,086,411

CNR,CPR & STATS CANADA TRAFFIC DATA & RAC TRAFFIC PROJECTIONS				YEAR 1975	YEAR 1976	YEAR 1977
GROSS TON-MILES	STATS.CAN.	GTM (millions)	ALL	266,941.9	273,360.4	282,114.8
NET TON-MILES	STATS.CAN.	NTM (millions)	ALL	138,576.6	142,178.5	148,900.3
RATIO of NTM / GTM	ALL NTM/GTM	NTM/GTM		0.519	0.520	0.528
IMP.GALS per 1000 Gross TM	TOTAL FUEL/ALL KGTM	I.G.per KGTM	ALL	1.6822	1.6995	1.7124
IMP.GALS per 1000 Net TM	TOTAL FUEL/ALL KNTM	I.G.per KNTM	ALL	3.2404	3.2676	3.2444

EMISSIONS FACTORS based on 1981-83 AAR "in-service" tests of 57 Locomotives.

ANNUAL EMISSIONS -- KILOTONNES		EMISSIONS FACTORS STD. FRGT. gm/IG	EMISSIONS FACTORS YARD & WORK gm/IG			
NOx	Kilotonnes NOx	248	277	113	117	121
HC	Kilotonnes HC	12	16	5.6	5.8	6.0
EMISSIONS -- KILOGRAMS/1000 NTM						
NOx	Kg./KNTM NOx			0.81	0.82	0.81
HC	Kg./KNTM HC			0.040	0.040	0.040

A CANADIAN FREIGHT RAILWAYS -- ANNUAL FUEL CONSUMPTION -- TRAFFIC STATISTICS -- EMISSIONS OUTPUT

YEAR 1977	YEAR 1978	YEAR 1979	YEAR 1980	YEAR 1981	YEAR 1982	YEAR 1983	YEAR 1984	YEAR 1985
436,291,345	440,024.087	459,310,810	455,812,403	443,860,816	391,445,966	411,156,794	437,852.458	427,680,176
436,291,345	440,024.087	459,310,810	455,812,403	443,860,816	391,445,966	411,156,794	437,852.458	427,680,176
36,784,996	36,986.113	39,794,091	37,338,811	32,560,311	29,261,667	26,029,182	26,732,542	26,613,387
10,010,070	8,870,030	10,387,399	8,894,352	9,946,747	8,607,211	8,110,350	8,822,318	8,486,384
483,086,411	485,880.230	509,492,300	502,045,566	486,367,874	429,314,845	445,296,325	473,407.318	462,779,947

YEAR 1977	YEAR 1978	YEAR 1979	YEAR 1980	YEAR 1981	YEAR 1982	YEAR 1983	YEAR 1984	YEAR 1985
282,114.8	285,196.6	307,917.7	308,474.5	309,174.6	275,560.4	298,510.0	329,577.2	314,688.0
148,900.3	151,036.8	163,660.8	164,347.3	163,925.8	147,380.4	158,815.9	176,411.9	168,080.4
0.528	0.530	0.532	0.533	0.530	0.535	0.532	0.535	0.534
1.7124	1.7037	1.6546	1.6275	1.5731	1.5580	1.4917	1.4364	1.4706
3.2444	3.2170	3.1131	3.0548	2.9670	2.9130	2.8039	2.6835	2.7533
121	122	128	126	122	108	111	118	116
6.0	6.0	6.3	6.2	6.0	5.3	5.5	5.8	5.7
0.81	0.81	0.78	0.77	0.74	0.73	0.70	0.67	0.69
0.040	0.040	0.039	0.038	0.037	0.036	0.035	0.033	0.034

PAC - PROJECTE

YEAR 1985	YEAR 1986	YEAR 1987	YEAR 1988	YEAR 1989 YEAR END OUTLOOK		YEAR 1990 TRAFFIC as '89 FUEL as '89	YEAR 1995
427,680,176	430,613,225	439,623,051	447,048,630	403,215,000 est.	STANDARD	403,215,000	394,094,288
					NEW LOCOS.	0	14,000,000
427,680,176	430,613,225	439,623,051	447,048,630	403,215,000 est.		403,215,000	408,094,288
26,613,387	25,877,445	26,634,460	26,169,010	24,793,000 est.		24,793,000	24,500,000
8,486,384	6,419,695	5,759,122	5,587,119	5,496,000 est.		5,496,000	5,000,000
462,779,947	462,910,365	472,016,633	478,804,759	433,504,000 est.		433,504,000	437,594,288

YEAR 1985	YEAR 1986	YEAR 1987	YEAR 1988	YEAR 1989 YEO		YEAR 1990 TRAFFIC as '89 FUEL as '89	YEAR 1995
314,688.0	319,685.7	342,647.5	340,200.5	308,425.0 est.		308,425.0	327,380.0
168,080.4	168,997.9	186,885.0	188,404.5	165,644.4 est.		165,644.4	178,446.1
0.534	0.529	0.545	0.554	0.537		0.537	0.545
1.4706	1.4480	1.3776	1.4074	1.4055		1.4055	1.3367
2.7533	2.7393	2.5257	2.5414	2.6171		2.6171	2.4522
						TRAFFIC as '89 FUEL as '89	
116 5.7	116 5.7	118 5.8	120 5.9	108 5.3		108 5.3	109 5.4
0.69 0.034	0.68 0.034	0.63 0.031	0.64 0.031	0.65 0.032		0.65 0.032	0.61 0.030

RAC - PROJECTED DATA

YEAR 1995	YEAR 2000	YEAR 2005		
394,094,288	328,223,170	262,391,009	STD.FRGT.LOCOS. I.G.	
14,000,000	84,000,000	154,000,000	NEW FRGT.LOCOS. I.G.	New low emissions replacement locos.added to High HP Fleet Annually @ 40 /Yr.effec.1/95
408,094,288	412,223,170	416,391,009	ALL FRGT.I.G.	TOTAL Fuel less YARD Switching & WORK
24,500,000	24,500,000	24,500,000	ALL YARD I.G.	
5,000,000	5,000,000	5,000,000	ALL WORK I.G.	
437,594,288	441,723,170	445,891,009	TOTAL FUEL I.G.	Calculated from I.G./KGTM for 1995-2005

YEAR 1995	YEAR 2000	YEAR 2005		
327,380.0	347,499.9	368,856.3	ALL MGTM	GTM's increase Annually @ 1.2 % after 1990
178,446.1	192,237.1	207,093.9	ALL MNTM	NTM's increase Annually @ 1.5 % after 1990
0.545	0.553	0.561	NTM/GTM	NTM/GTM increases Annually @ 0.3 % after 1990
1.3367	1.2711	1.2088	IG/KGTM	I.G./KGTM reduces Annually @ 1.0 % after 1990 due to operational fuel efficiency programs.
2.4522	2.2978	2.1531	IG/KNTM	

EMISSIONS FACTORS

For New low emissions replacement units added to fleet starting Jan.1995.		Estim. % Red'n.	NEW FRGT. gm/IG
	NOx	10	223.2
	HC	--	12

109	108	108	Kilotonnes NOx
5.4	5.4	5.5	Kilotonnes HC
0.61	0.56	0.52	Kg./KNTM NOx
0.030	0.028	0.026	Kg./KNTM HC

APPENDIX 1B

SPREADSHEET DATA
FOR
RAILWAY PASSENGER FUEL, TRAFFIC, & EMISSIONS

RAILWAY ASSOCIATION
OF
CANADA

NOVEMBER 1989

CNR HQ MP&CE
WGB 14/11/89
Lotus2.01"PSGRCCME"

RAILWAY ASSOCIATION of CANADA — CANADIAN PASSENGER

DATA SOURCES :-

STATS. CANADA Annual Report for ALL Rlwys.

			YEAR 1975	YEAR 1976	YEAR 1977	YEAR 1978	
FUEL CONSUMPTION DATA							
PASSENGER SERVICE	- I.G.	ALL	64,408,344 High ????	49,170,806	48,396,405	49,276,954	
TOTAL FUEL - ALL PASSENGER OPER'NS.	- I.G.	ALL	64,408,344	49,170,806	48,396,405	49,276,954	
STATS CANADA TRAFFIC DATA & RAC TRAFFIC PROJECTIONS			YEAR 1975	YEAR 1976	YEAR 1977	YEAR 1978	
PASSENGER CAR-MILES	Car-Miles	CNR	104,135,392	98,015,663	94,665,088	89,815,916	
		CPR	23,946,004	23,264,088	22,241,737	20,399,434	
		CNR+CPR-->	128,081,396	121,279,751	116,906,825	110,215,350	VIA-->
		OTHER	11,945,139	12,701,814	13,325,002	12,213,185	
		ALL	140,026,535	133,981,565	130,231,827	122,428,535	
IMP.GALS per PASS. CAR-MILE	I.G.per Car-Mile	ALL	0.4600 High ????	0.3670	0.3716	0.4025	

EMISSIONS FACTORS based on 1981-83 AAR "in-service" tests of 57 Locomotives.

ANNUAL EMISSIONS -- KILOTONNES	EMISSIONS FACTORS PASS. 1975-86 gm/IG	PASS. 1987+ gm/IG				
NOx	277	248	High ???? 17.84	13.62	13.41	13.65
HC	16	12	1.03	0.79	0.77	0.79
	"Blower"	"Turbo"				
EMISSIONS -- GRAMS/Car-Mile						
NOx			127.4	101.7	102.9	111.5
HC			7.4	5.9	5.9	6.4

Preliminary

1. 4 NOV 1989

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CANADIAN PASSENGER RAILWAYS -- ANNUAL FUEL CONSUMPTION -- TRAFFIC STATISTICS -- EMISSIONS OUTPUT

YEAR 1978	YEAR 1979	YEAR 1980	YEAR 1981	YEAR 1982	YEAR 1983	YEAR 1984	YEAR 1985
49,276,954	44,247,241	44,652,620	41,020,552	34,450.012	25.946,202 Low ??	25,390,172 Low ??	57,320,797 High ????
49,276,954	44,247,241	44,652,620	41,020,552	34,450.012	25,946,202	25,390,172	57,320.797

YEAR 1978	YEAR 1979	YEAR 1980	YEAR 1981	YEAR 1982	YEAR 1983	YEAR 1984	YEAR 1985
89,815,916	16,675,939	2,317,915	2,267,270	2,306,557	2,564,308	2,359,483	2,341,569
20,399,434	2,168,145	833,801	788,143	604,341	255,493	215,524	260,200
110,215,350 V(A--)	90,100,000	101,994,000	100,231,000	78,722,048	71,761,112	72,049,696	76,292,079
12,213,185	12,311,891	11,868,254	12,376,108	13,268,472	13,024,120	12,946,529	12,594,967
122,428,535	121,255,375	117,013,970	115,662,521	94,901,418 Corr.from Stats.Can.	87,605,033 Corr.from Stats.Can.	87,571,232 Corr.from Stats.Can.	91,488,815 Corr.from Stats.Can.
0.4025	0.3649	0.3816	0.3547	0.3630	0.2962 Low ??	0.2899 Low ??	0.6265 High ????
13.65	12.26	12.37	11.36	9.54	Low ?? 7.19	Low ?? 7.03	High ???? 15.88
0.79	0.71	0.71	0.66	0.55	0.42	0.41	0.92
111.5	101.1	105.7	98.2	100.6	Low ???? 82.0	Low ???? 80.3	High ???? 173.5
6.4	5.8	6.1	5.7	5.8	4.7	4.6	10.0

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PAC - PROJECTED DATA

YEAR 1986	YEAR 1987	YEAR 1988	YEAR 1989 YEAR END OUTLOOK	YEAR 1990 VIA = 1/2	YEAR 1995 NO CHANGE	YEAR 2000 NO CHANGE	YEAR 2005 NO CHANGE
49,279,500 High ????	32,000,000 est.	32,000,000 est.	32,000,000 est.	18,635,731	18,635,731	18,635,731	18,635,731
49,279,500	32,000,000 est.	32,000,000 est.	32,000,000 est.	18,635,731	18,635,731	18,635,731	18,635,731

YEAR 1986	YEAR 1987	YEAR 1988	YEAR 1989 YEO	YEAR 1990 VIA = 1/2	YEAR 1995 NO CHANGE	YEAR 2000 NO CHANGE	YEAR 2005 NO CHANGE
1,977,858	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
198,906	200,000	200,000	200,000	200,000	200,000	200,000	200,000
74,128,250	67,223,000	72,045,000	72,000,000	36,000,000	36,000,000	36,000,000	36,000,000
11,651,992	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000	12,000,000
87,957,005 Corr.from Stats.Can	81,423,000 estimated	86,245,000 estimated	86,200,000 estimated	50,200,000	50,200,000	50,200,000	50,200,000
0.5603 High ????	0.3930	0.3710	0.3712	0.3712	0.3712	0.3712	0.3712
High ???? 13.65	7.94	7.94	7.94	4.62	4.62	4.62	4.62
0.79	0.38	0.38	0.38	0.22	0.22	0.22	0.22
High ???? 155.2	97.5	92.0	92.1	92.1	92.1	92.1	92.1
9.0	4.7	4.5	4.5	4.5	4.5	4.5	4.5

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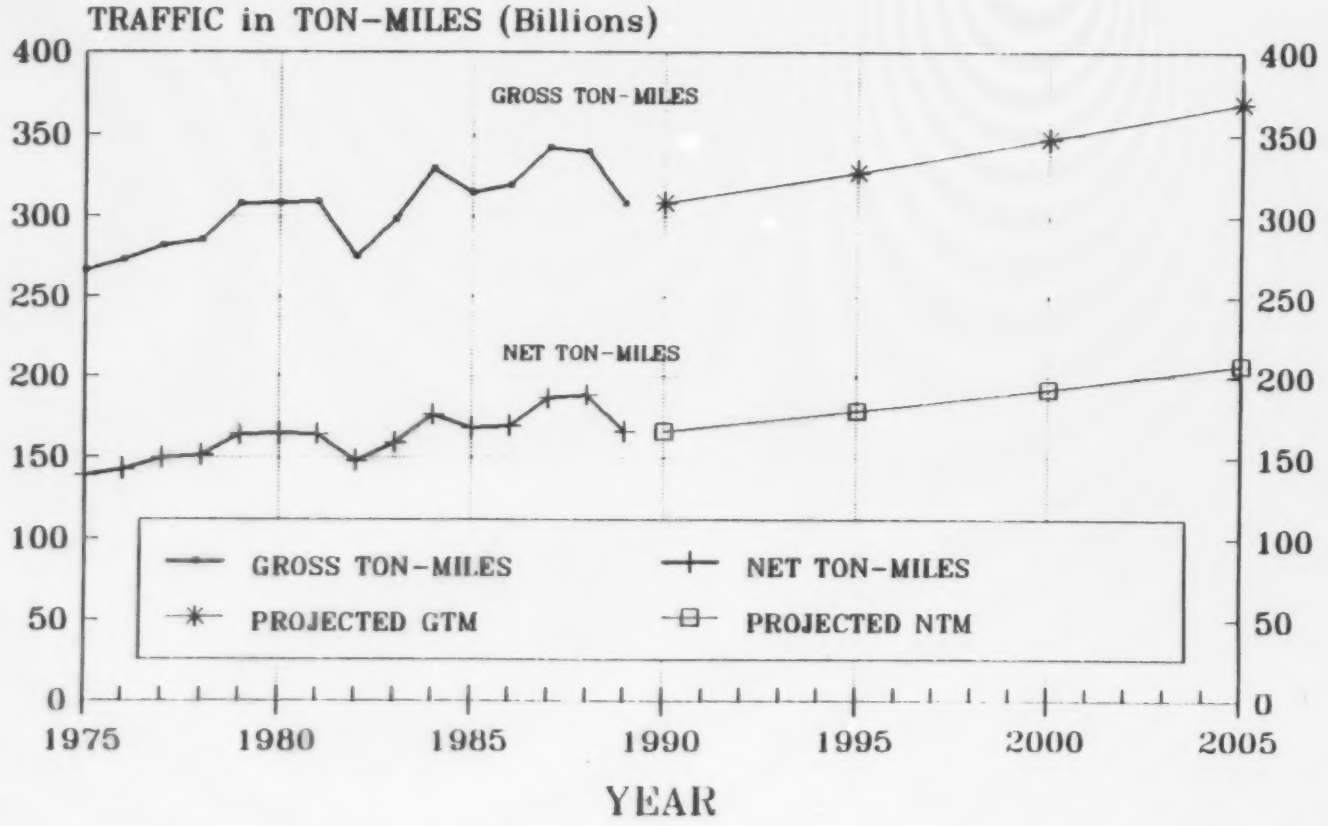
APPENDIX II

GRAPHICAL PRESENTATION
FOR
RAILWAY FREIGHT FUEL, TRAFFIC, & EMISSIONS

RAILWAY ASSOCIATION
OF
CANADA

NOVEMBER 1989

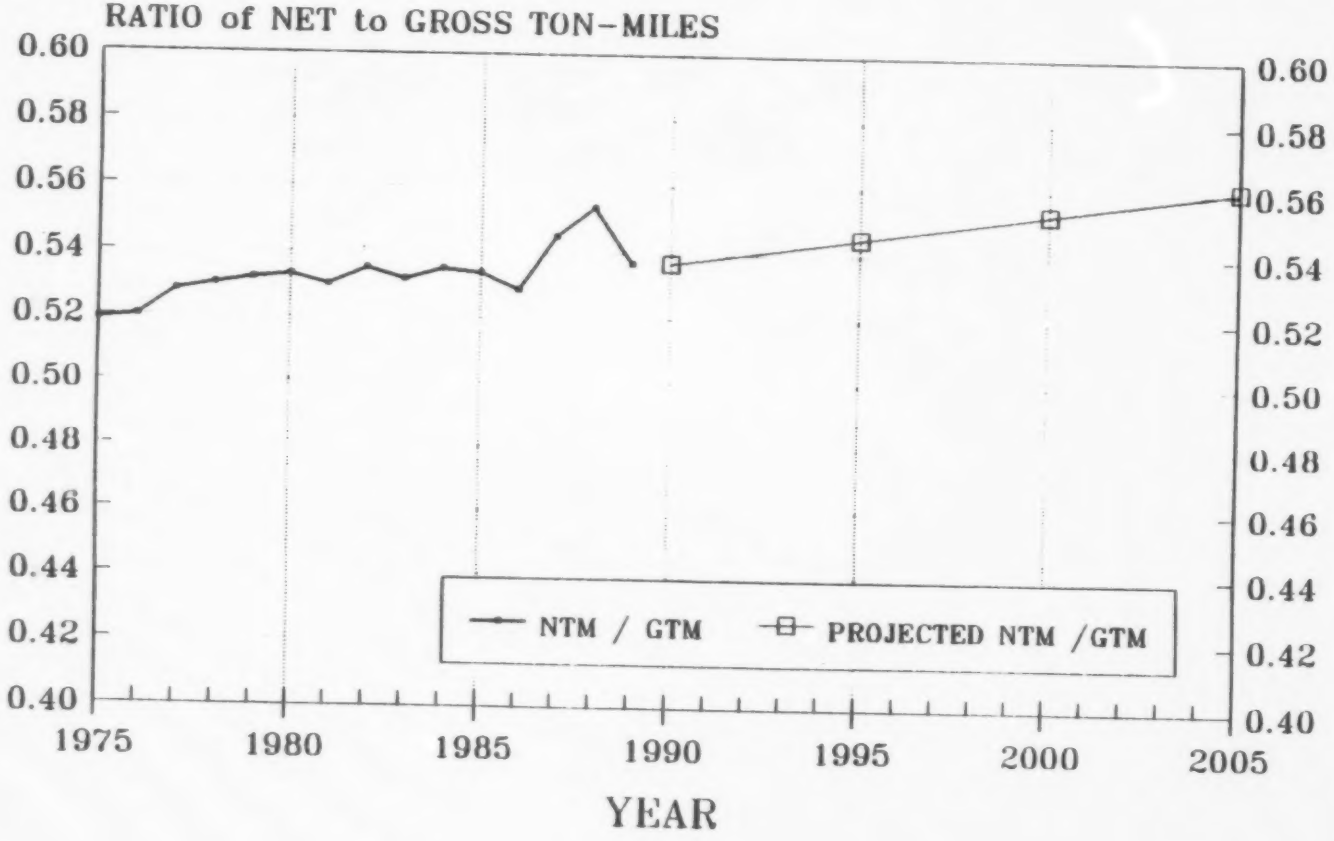
CANADIAN RAILWAY FREIGHT TRAFFIC
YEARS 1975 to 2005



GRAPH 1

CNR HQ MP&CE
WGB 10/11/89
HG:"RACTRAF"

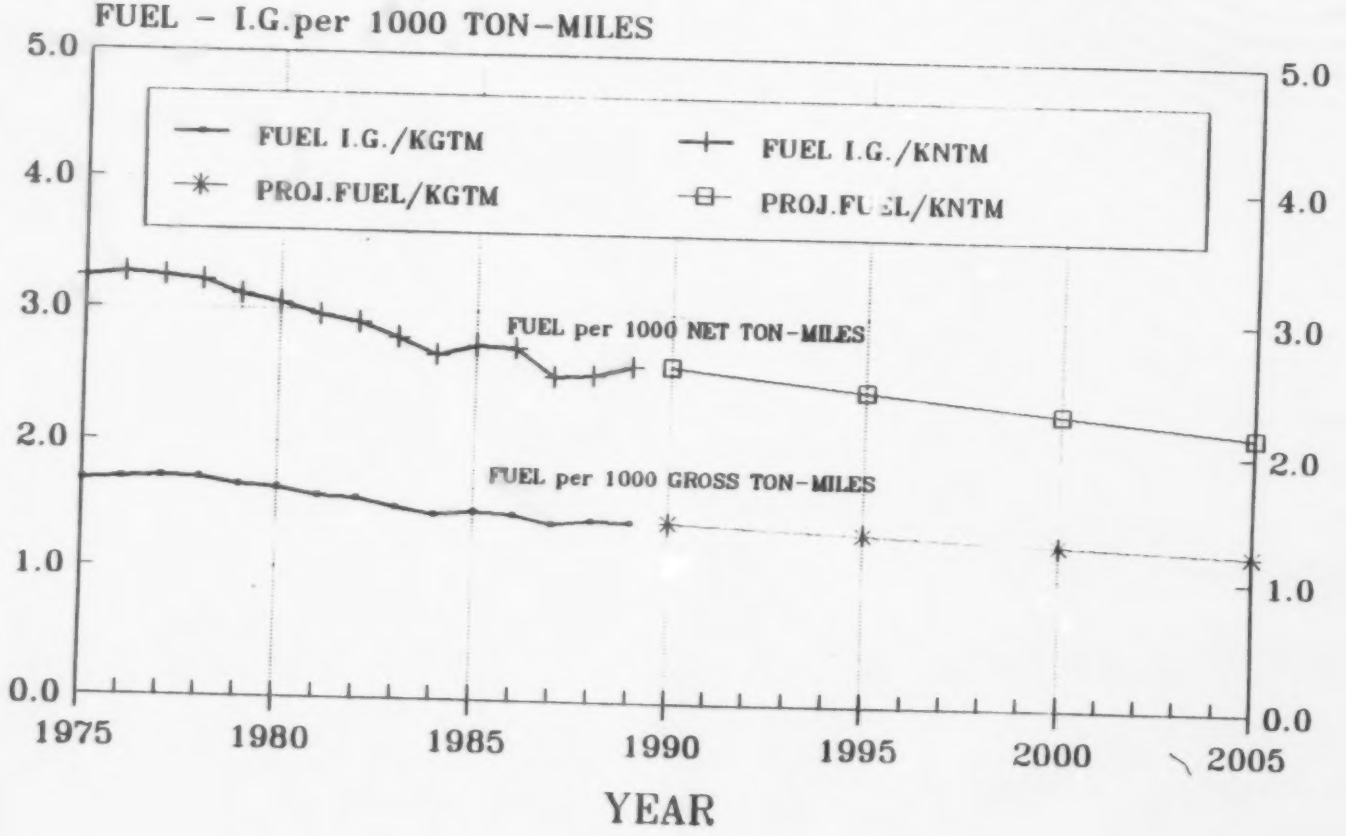
CDN. RAILWAY FREIGHT NET to GROSS RATIO
YEARS 1975 to 2005



GRAPH 2

CNR HQ MP&CE
WGB 10/11/89
HG:"RACNtoG"

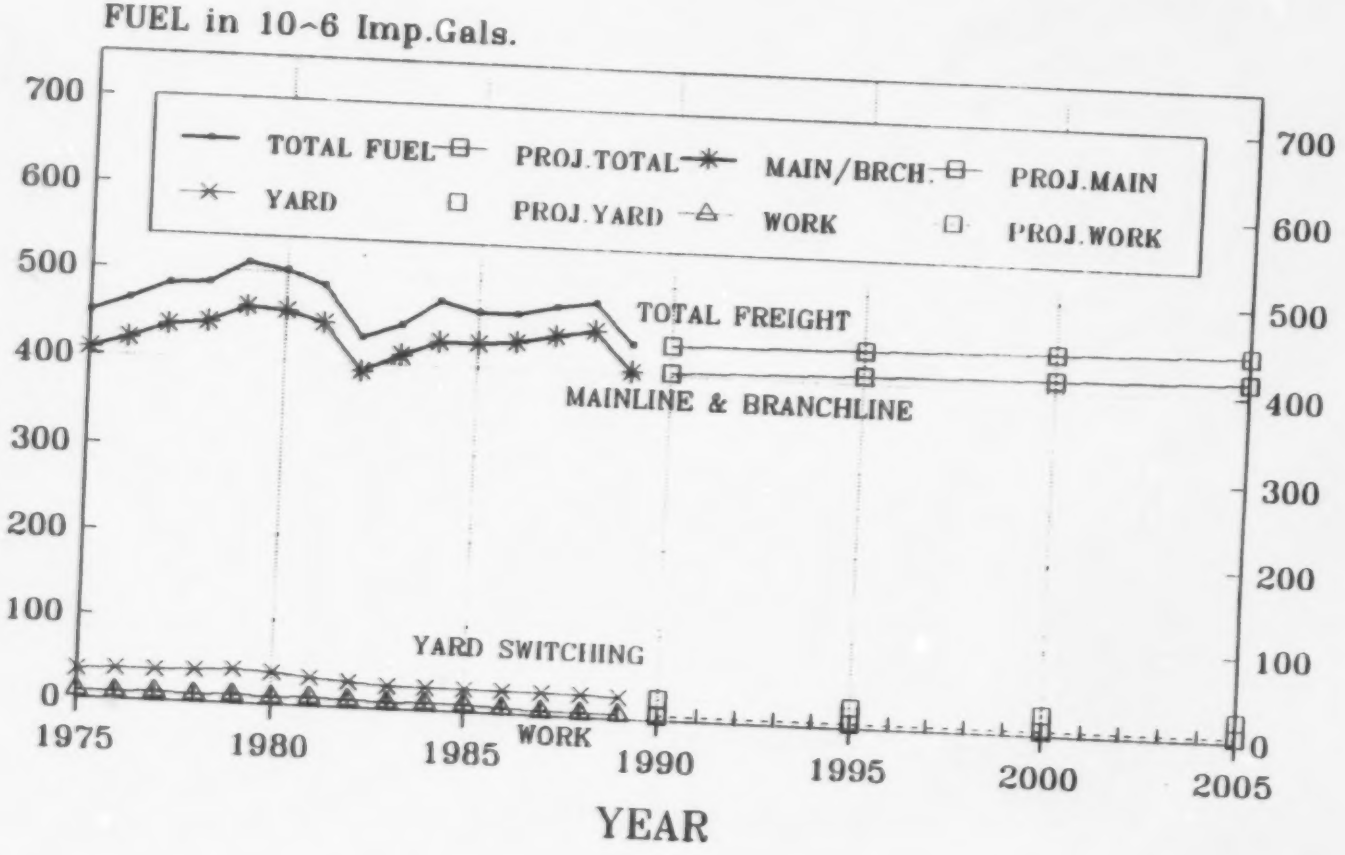
CDN.RAILWAY FREIGHT FUEL per TON-MILE
YEARS 1975 to 2005



GRAPH 3

CNR HQ MP&CE
WGB 10/11/89
HG:"RAC_IGTM"

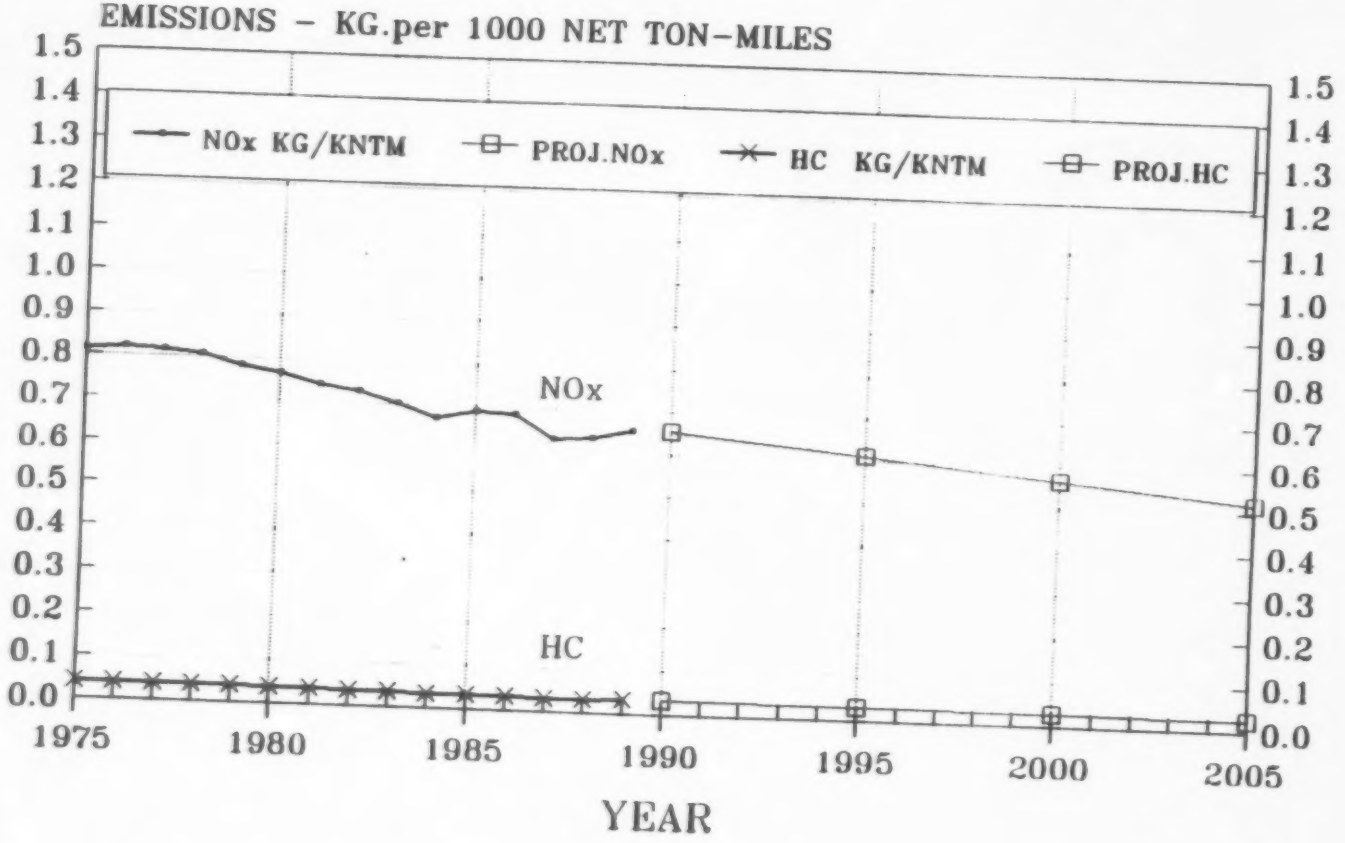
CANADIAN RAILWAY FREIGHT FUEL
YEARS 1975 to 2005



GRAPH 4

CNR HQ MP&CE
WGB 12/11/89
HG:"RACFUEL"

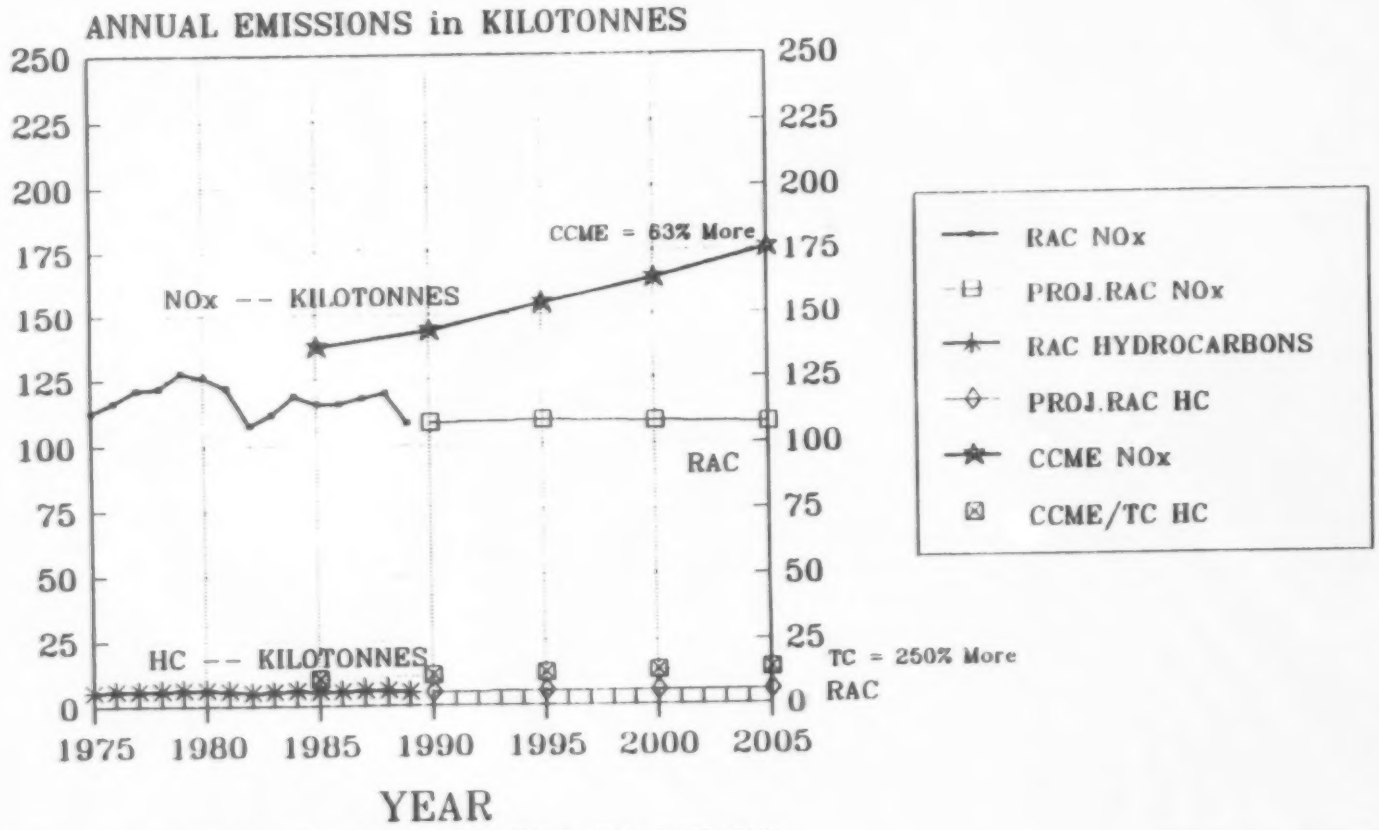
CDN.RLWY.FREIGHT EMISSIONS/NET TON-MILE
YEARS 1975 to 2005



GRAPH 6

CNR HQ MP&CE
WGB 12/11/89
HG:"RAC/NTM"

CANADIAN RAILWAY FREIGHT EMISSIONS
YEARS 1975 to 2005



NOTE:- RAC Excludes Emissions for PASSENGER TRAINS

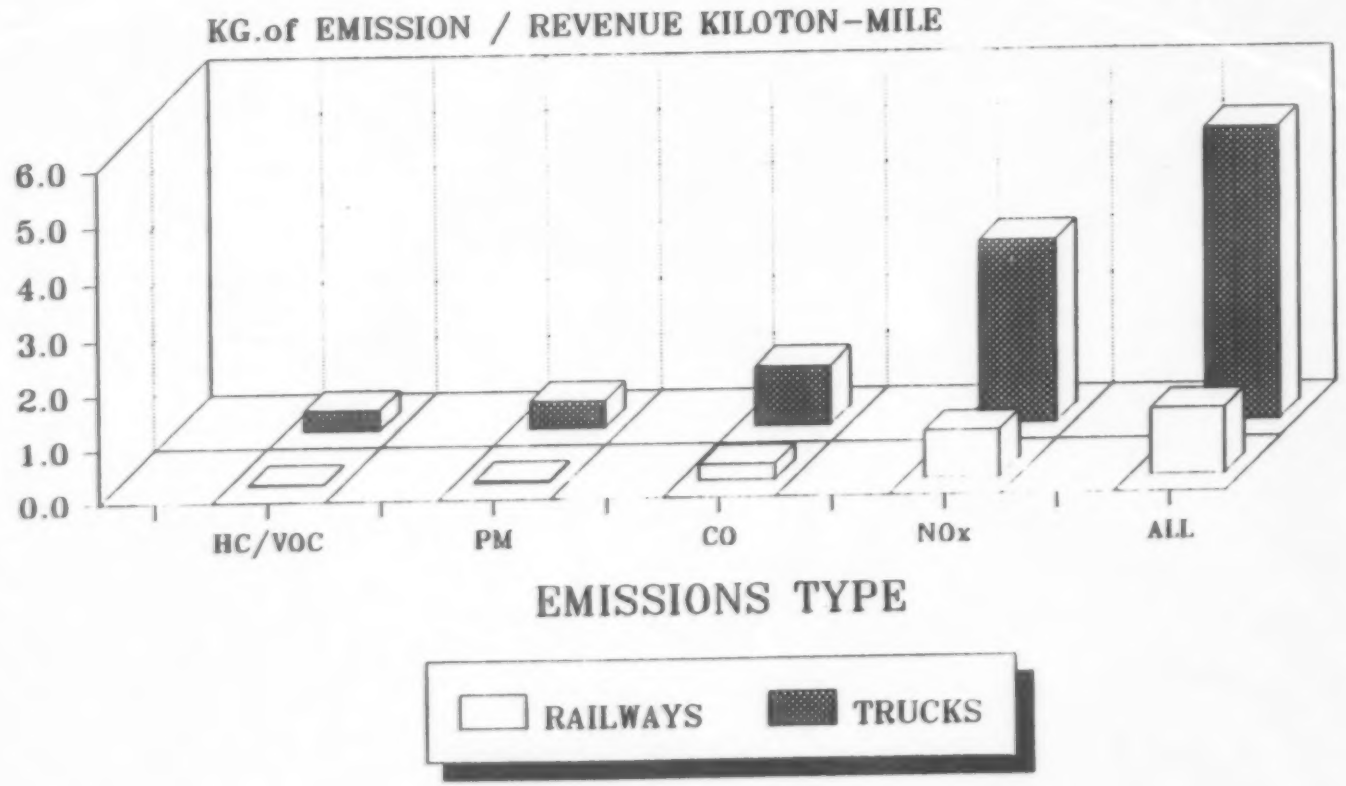
Approx. 8 KT NOx in 1989 & 5 KT NOx in 2005

GRAPH 5

CNR HQ MP&CE
WGB 14/11/89
HG:"RACEMIS"

1984 U.S. MODAL EMISSIONS SUMMARY
EMISSIONS per REVENUE KILOTON–MILE

Ref:AAR Analysis of RADIAN/EPA Report/88



CNR HQ MP&CE
WGB Rev.17/11/89
HG:"RADIAN1"

GRAPH 7

APPENDIX III

NOTES on DERIVATION of DATA
FOR
RAILWAY FREIGHT FUEL, TRAFFIC, & EMISSIONS

RAILWAY ASSOCIATION
OF
CANADA

NOVEMBER 1989

APPENDIX III

Railway Association of Canada
Railway Locomotive Emission Inventories

Notes on Derivation of Data - Freight Service

1) Traffic Data - Historical 1975 to 1989

- Gross Ton-Miles and Net Ton-Miles were reviewed for CNR and CPR from Annual Report on Operating Statistics submitted to the CTC. Data for 1989 projected forward to Year End from Semi-Annual results.

- Statistics Canada Annual Reports was used for ALL Railways. For consistency with historical data, figures were converted to Imperial measure where required.

- The difference between ALL and (CNR + CPR) was taken to be balance of industry, i.e. OTHER.

- OTHER was estimated for 1987-1989 since the Statistics Canada Annual report is not yet issued.

- OTHER in this decade is typically about 8% of the Total. A minor correction was made to OTHER GTM in years 1984 and 1986 due to obviously incorrect published figures.

- Statistics Canada Freight Traffic data for ALL Railways is concluded to be reliable for the purpose intended.

2) Traffic Data - Projected 1990 to 2005

- Projections are fundamentally based on the long term trend between 1975 and 1989.

- The starting point for 1990 was assumed to be the same as for 1989 YEO, i.e. depressed traffic expected to continue for one more year. The 1989/1990 traffic loss was taken to be non-recoverable.

- Net Ton-Miles long term growth was taken as 1.5% compounded annually for 1991 to 2005.

- Improvement of Net to Gross Ratio was taken as 0.3% compounded annually for 1991 to 2005.

- Resultant Growth of Gross Ton-Miles for 1991 to 2005 is then 1.2% compounded annually.

A/Misc8/WGB21/fj

3) Fuel Data - Historical 1975 to 1989

As per Traffic Data, the Fuel Data for CNR and CPR was obtained from CTC annual submissions.

- Statistics Canada is the source of data for ALL Railways.
- Fuel labelled by Statistics Canada as "Crude Oil" is, in fact, Tar Sands derived diesel fuel and is therefore added to the Diesel Oil total.
- OTHER was estimated for 1987-1989 (less than 10% of total).
- The Statistics Canada Fuel Data for Freight service is concluded to be sufficiently accurate for the purpose of national emissions.

4) Fuel Data - Projected 1990-2005

- Projections were calculated from long term trend of reduction of I.G. per 1000 GTM for 1975-1989.
- The fuel rate for Main Line and Branchline Freight was taken as 99% of the preceeding year for 1991-2005.
- The projected rate of change is about 1/2 that of long term trend, i.e. a conservative estimate.
- The starting point for fuel rate in 1990 assumed to be same as 1989 YEO, i.e. a conservative approach since 1989 rate is high due to traffic downtown.
- The projected TOTAL fuel in Gallons was calculated from Rate X GTM. Mainline and Branchline fuel is calculated from TOTAL less YARD and WORK.
- For 1995 to 2005, Fuel for CNR and CPR is subdivided between older locomotives and new "low emissions" replacement units being added to the fleet. Each new locomotive is projected to consume 350,000 IG per year.

5) Fuel Data - Provincial Distribution

Older Statistics Canada and CTC Annual reports (to 1981) clearly showed that the Provincial allocations of fuel were based on Deliveries at Fuelling Stations. More recent data is not clear on this point. There is a distinction between provincial consumption and provincial deliveries. For instance, a significant amount of the fuel delivered and placed in locomotive fuel tanks in urban Western Quebec (principally Montreal) is consumed in rural Eastern and Northern Ontario.

More research is required to ensure that the CCME provincial emission breakdown is truly based upon consumption, not deliveries.

A/Misc8/WGB21/fj

Such a consumption breakdown is currently made by Canadian railways for the payment of provincial fuel taxes. It is based upon Gross-Ton-Miles and other traffic indicators in each province.

6) Fuel Data - Urban/Rural Distribution

It is clear that the vast majority of fuel consumed by Canadian Railways is in the rural areas. The category of Yard Switching, however, (about 6% of Total) can be considered to be more urban in nature. Not all by any means is in large population centres, as such yard switching also occurs in the numerous small "Railway Towns" of Canada. These areas are arguably more rural than urban in character.

More detailed study will be required to provide a numerical breakdown of Urban/Rural fuel distribution. RAC will examine traffic breakdown by subdivision as a reasonable approach to intra-provincial emissions distribution.

7) Emission Factors - Historical 1975 to 1989

Emission test information on Medium speed diesel engines as used by locomotives is somewhat limited.

RAC has reviewed all available data to determine trends:

i) EPA - Southwest Research Institute (SWRI)
3 Locomotives - 1972

ii) AAR-SP-ATSF-UP Railways
4 Locomotives - 1972

iii) EMD - 18 16V-645E Engines, 1973 to date
(Unpublished)

iv) Bombardier Ltd.
1 Engine - 1979 (unpublished)

v) EMD and GE published data on current engines
(ASME papers, etc.)

vi) AAR-SWRI (California Baseline Tests)
2 Engines - 1989 (unpublished)

vii) AAR-SP-ATSF-UP-MOPAC
57 Locomotives - 1981-1983

From this review, the data arising from the large sample of 57 locomotives done by AAR in 1981-1983 presents a reasonable balance between all data sources.

From applying a throttle notch duty cycle which matches Canadian Railways fuel consumption, sets of test derived emission factors have been determined.

A/Misc8/WGB21/fj

It was found that the factors for Turbocharged 2 Cycle (GM/EMD) and the latest 4 Cycle (GE/Alco-Bombardier) diesel engines are not sufficiently different to merit differentiation. The GM/EMD factors have been used since both CNR and CPR High Horsepower mainline locomotives are principally GM/EMD turbocharged 3000 to 3800 HP.

For Yard Switching and Work Train service, test derived factors for the GM non-turbocharged "Blower" engine are utilized, again reflecting the principal usage.

8) Emission Factors - Projected 1990 to 2005

Emission awareness by the new locomotive manufacturers will eventually result in improved engine emissions output. This is viewed as a long term target.

To reflect some potential progress in this regard, a reduction of 10% in the NOx factor has been postulated for locomotives delivered for 1995. It is assumed that CO, HC, and Particulate Matter factors are unchanged, i.e. kept under control instead of rising as currently accompanies NOx reduction strategies. SO2 and CO2 are fuel property related and assumed constant.

The replacement rate of locomotives in 1995 and beyond is assumed to be 40 locomotives per year. The capital expenditures are very large ($80 million/year). This assumed replacement rate is not to be construed as a commitment to these or any purchases in the future. Further, successful achievements by locomotive manufacturers in diesel engine research, development and commercialization of products are not controlled by the Canadian Railways.

This being said, however, RAC submits the above projected improvements as reasonable expectations for planning purposes. The effect is about a 4% reduction in NOx emission in 2005 compared to a nil purchase program. In either case, however, NOx in kilotonnes is less in 2005 than the 1987 Baseline Year required by international agreement.

More importantly, the NOx projected by RAC for 2005 is significantly lower than the CCME estimate.

The HC projected by RAC is well under half of that shown by Transport Canada in Report # TP-9773E.